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It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past six years. The Coral Atoll Program is a part of SIM.

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Preliminary Report on Land Animals at Onotoa Atoll, Gilbert Islands

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PRELIMINARY REPORT ON LAND ANIMALS AT ONOTOA ATOLL, GILBERT ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

Edwin T. Moul
Rutgers University
The State University
of New Jersey
New Brunswick, N. J.
February 1954.

PRELIMINARY REPORT ON LAND ANIMALS AT ONOTOA ATOLL, GILBERT ISLANDS

This represents the first two parts of the preliminary report on the work of the General Naturalist on the Pacific Science Board's 1951 Expedition to Onotoa in the Gilbert Islands. The project was supported by funds granted to the National Academy of Sciences by Contract N7onr-291(04), NR 388-001 with the the Office of Naval Research. The generous cooperation of the U. S. Navy Department, the U. S. Coast Guard, and the Military Air Transport Service is acknowledged.

The author is grateful for the aid and assistance given by Mr. Harold J. Coolidge, Mrs. Lenore Smith and Miss Ernestine Akers. The cooperation and kindness of the British Colonial Government and its local representative, Mr. Richard Turpin and his wife added much to our comfort and success. The advice and assistance of my associates was a constant source of help and encouragement.

Part I. Land Vertebrates of Onotoa Atoll, Gilbert Islands

As general naturalist of the 1951 Pacific Science Board's expedition to Onotoa in the Gilbert Islands it was my duty to collect information about and specimens of all the land animals and plants on the island and to study the ecology of the fresh water and marine algae. In order to treat this material in a systematic manner I have divided my report into four sections. The first of these is the report on the land vertebrates collected and observed on the atoll of Onotoa from June 24 to August 30, 1951.

Due to my hurried preparation, I had very little time to search the literature for known facts about the flora and fauna of the Gilberts. Thus upon my return, I found that some information and specimens that should have been gathered were overlooked. Since very little has been published on the biota of this island group, the information and specimens gathered are of value in extending our knowledge of the distributional patterns of this life in the South Pacific.

In the following accounts of the individual species of vertebrates, I have included all the facts and observations recorded in my field notes. Because of my many other responsibilities, these accounts in many cases are correspondingly brief; most of the information was gathered "on the run."

The birds were identified by the author. Credit for other determinations are given with each group. The native names were supplied by Baru, our cook, and verified in most cases by James Redfern, our interpreter.

The author wishes to thank Dr. David H. Johnson of the United States National Museum staff for traps and other equipment used in collecting the rats; Dr. Joseph P. E. Morrison, also of the Museum staff, for providing the

fire-arms and ammunition for the collection of birds and for his excellent advice and encouragement while making preparations for the trip; and Dr. Waldo Schmitt, who has been extremely helpful on several of my visits to the museum and has assisted in securing the taxonomic information. The cooperation and kindness of the people of Onotoa in securing specimens is appreciated and acknowledged. Last and most important, due recognition should be given to the Office of Naval Research for making the expedition possible and for providing the opportunity to secure valuable basic scientific information on atolls and their ecology. All specimens have been deposited in the U. S. National Museum with provisions made for duplicates to be sent to the Bernice P. Bishop Museum in Honolulu.

MAMMALS

Rattus exulans exulans (Peale), Rat, "te gemoi."

Identification of this native rat was made by Dr. David H. Johnson of the United States National Museum. Four adults, three males and one female, and three young in various stages of growth were collected. The fact that these immature specimens were taken at intervals spanning our stay on the island is evidence that these animals bred from June through August. The specimens taken have been placed in the U. S. National Museum collection as numbers 294547 to 294553.

These rodents are not numerous and we hear no complaints from the natives about them. The number of cats, dogs and pigs around the village certainly keep these animals from becoming pests. I believe also that the construction of the native houses, with floors about two feet from the ground, the extreme cleanliness and order around the house sites, with no accumulation of rubbish, is also a factor in the control of these animals.

The first week of our stay on the island, pits were dug for garbage and latrines. These pits trapped great numbers of hermit crabs and a few rats. Spring traps placed in the kitchen caught several specimens, but on several occasions the activity of some local cat or dog left me only the tail.

At night there was a great amount of rustling noise in the dead leaves of the Scaevola thickets, which at first I attributed to rats, but most of which was later found to be caused by the nocturnal activity of the hermit crabs. Only a few times did I actually see these rodents running from thicket to thicket or scurrying under the rubbish in the thickets. When the camp was dismantled at the end of our stay, there was evidence of several nests under the packing cases in the supply tent. We suffered little damage to our supplies from these rodents. I feel certain from all the evidence I could find that the rat is not abundant enough on Onotoa to be a pest nor is it destructive to food.

Dogs.

The dogs are nondescript, short-haired and medium sized. They are very numerous around the villages and during the heat of the day were found sleeping or resting on loose sand in shady spots along the village street. They

rarely paid much attention to the "foreigners." Most of their food seemed to consist of scraps from the family table. Several nights I was awakened by noise from the kitchen and on investigating I found dogs foraging in the garbage can which had not been emptied.

Cats.

These animals were common in the villages. At the village of Aiaki our slumber was disturbed by the horrible crying made by cats congregating in the Maneaba, the community house, where visitors are housed and entertained.

Pigs.

Pigs were not common, but in each village there were a few stockades built of logs to confine one or two. These stockades were usually placed on the opposite side of the road away from the houses and the lagoon shore. An ordinance of the Magistrate made it necessary for pigs to be either confined in pens or tied to stakes to prevent their wandering about. On one of the field trips on the island of Tabuarorae, I saw one large specimen wandering about, rooting in the rubbish, dragging a long rope behind it which it had obviously broken.

We were told that pigs are used for food only on special feast days, when they are roasted in pits lined with pre-heated stones. I am sure the muck in the pig pens is one of the places where the common house fly breeds.

BIRDS

Fifteen species of birds were observed on Onotoa Atoll during our stay there. As one would expect of an oceanic coral island, these species were mainly oceanic birds or migratory shore birds. Only one species of land bird, other than the domestic chicken, was observed and this was a migratory species. The nomenclature is based on Baker (1951)*.

Phaethon rubicauda rothschildi (Mathews), Red Tailed Tropic Bird.

Only one specimen of this bird was seen. It was observed flying low over the camp area on August 10. The trailing red tail feathers and the rosy coloration on breast feathers were quite evident.

Fregata ariel ariel (Gray), Least Man-O-War Bird.

These birds were observed soaring only at rare intervals, and were usually seen at times of high wind velocities and overcast skies. The white patches on the ventral flanks of the males were visible. The fork of the tail was rarely visible, since it was held closed, it formed a straight line with the body. As many as five birds were seen at one time. They are reported to nest in the large Pisonia trees at the extreme south end of the atoll on Tabuarorae Island. During our stay none were observed on this island.

*Baker, R. H., 1951, Avifauna of Micronesia, its origin, evolution and distribution. U. of Kan. Pub. Mus. of Nat. Hist. 3:1-359.

Demigretta sacra sacra (Gmelin), Reef Heron, "te kai."

A fairly common bird seen the whole length of the Atoll. White, blue and variegated individuals were present in the ratio of 3 to 2 to 1. A careful check on peculiarly marked, variegated individuals indicated that these birds are restricted to certain distinct territories along the reef and shore. Most of the birds fed at low tide along the seaward reefs and on the exposed reef flats between the various islands of the atoll. At high tide occasional individuals were observed foraging along the beach. They often capture food by standing motionless in the pools that remain on the dry reef at low tide. They wait for the organisms in these pools to move, then they capture the animal with a rapid jab of the beak. This species was less frequently seen on the lagoon side of the islands. On a number of occasions they were flushed from babai (taro) pits or the area surrounding these pits. They were also seen perched in coconut trees preening their feathers. On Aonteuma, the uninhabited northernmost island of the atoll, a structure resembling a nest was observed in a coconut palm. My attention was attracted to it by the circling and calling of a white specimen of this species. As long as I remained under the tree it continued circling and perching, uttering a loud gutteral call. The nest was placed in a coconut tree on the petioles of several leaves and was built of dead flower stalks of the coconut.

Two specimens were collected, #207, a blue individual, and #254, a white phase. This last bird was feeding along the beach at high tide and had fragments of crustacea in its stomach.

Gallus gallus (Linnaeus), Jungle fowl, "te moa."

I have used this name for the half wild, semi-domestic chicken observed around the villages. The adult males have the typical plumage of the Jungle Fowl, but the hens show a mixture of domestic strains. All are small and lay small eggs. Many of the hens were followed by flocks of chicks in various stages of growth.

The natives apparently do not eat the eggs and inquiry revealed they rarely use the mature birds for food. Both eggs and chickens were offered to us for our use. A whole roasted chicken was served to us on one occasion at a native feast. The feathers are utilized in decorating fans woven from pandanus.

Pluvialis dominica fulva (Gmelin), Pacific Golden Plover; "te kun."

A few birds of this species were observed feeding on the reef at low tide on July 12th. The number of these birds increased during August until small flocks were seen all along the seaward reef and on the lagoon shore. This was the only species of shore bird regularly flushed from sand and grass areas between the scattered coconut trees inside the beach rampart. A male was shot on the seaward reef on August 19 (#275).

Numenius phaeopus variegatus (Scopoli), Whimbrel.

These birds were exceedingly wary and none were collected. A few birds were noticed in late July, but the number increased in August. Individuals

were usually seen on the exposed reef flats at the south end of the northern Island. Abenekeneke, a small uninhabited island between the large North and South Islands, was the favorite gathering place for a small flock which was frequently encountered resting under the palms on the seaward side. This species was identified by the black line through the eye and the white back and rump, and barred tail.

Heteroscelus incanus (Gmelin), American Wandering Tattler, "te kiriri."

This was the noisiest of the shore birds and was always present on the reef and lagoon shore, becoming very common in late August. It was characterized by quick movements and frequent teetering of the body, particularly as it alighted. An immature specimen was collected on August 18 on the reef flat at the south end of the North Island (#277).

Arenaria interpres interpres (Linnaeus), Ruddy Turnstone, "te kitiba."

These shore birds were present on the island when we arrived in June. They associated with the Plovers and Tattlers, and flew with them, but fed in separate flocks. In June there were only three or four birds in a group. Late in August the size of the flocks had increased to 8 or 10 birds and every section of the reef seemed to have its own flock. They fed in close formation along the beach, turning over shells, algae, leaves and drift. At low tide they fed on the drying seaward reef. The Tattlers and Plovers were frequently seen on the lagoon shore, but the Turnstones preferred the rocky shore and reef of the seaward side of the atoll, also utilizing the cobble and shingle reef flats between the larger islands. One specimen was taken on the seaward reef, August 18 (#274).

Sterna sumatrana sumatrana Raffles, Black Naped Tern, "te ngutu."

Two colonies of these terns were found on each of the two small islands, Abanekeneke and Nanntabuariki. They seemed to prefer resting on the coarse coral gravel ramparts on the seaward side of these two islands. This species was observed habitually fishing in the shallow water at the northern end of the lagoon. Birds were seen returning to the colonies near the central part of the atoll, carrying fish crosswise in their beaks. When the Long Tailed New Zealand Cuckoo was flushed from shrubbery on Nanntabuariki, a group of these terns attacked and chased the Cuckoo into another thicket, in much the same manner that I have observed terns attacking gulls in eastern Massachusetts. One specimen, #262, was brought in by a native. The bird had a heavy deposit of orange colored fat between the skin and muscle layer.

Sterna fuscata oahuensis Bloxham, Sooty Tern.

The only specimen seen of this species was dead. It was washed up on the seaward beach on August 14, 1951. No living individuals were seen on the atoll.

Thalasseus bergii pelecanoides (King), Crested Tern; "te kabiniwa."

Only two individuals of this species were seen, both on August 19 on the seaward reef. Both birds were resting on large coral boulders facing the reef front. One bird, a male (#276), was collected. The second individual was an immature bird and flew out to sea when disturbed.

Anous stolidus pileatus (Scopoli), Common Noddy Tern; "te nan."

One specimen was collected (#49). This was the commonest bird of the Atoll. Colonies were scattered the whole length of the central area of the large North Island. They were present in large numbers on the two larger southern islands of Aiaki and Tabuarorae. During the middle of the day many birds were observed perched in palm and pandanus, resting and preening, but there always seemed to be some restless individuals moving out to sea and back again. The greatest movement of birds occurred in the early morning and late afternoon, when great numbers constantly moved back and forth between the roosting area and the sea, the reef or the lagoon.

This species and the smaller species of Noddy were frequently seen feeding on an ebbing tide, particularly if the sea beyond the coralline ridge was rough. On these occasions the birds could be observed up and down the shore as far as the eye could see. They hovered low over the reef, darting about, dropping to pick their food from the surface of the water or just below the surface, not diving and submerging like our common Atlantic Tern. Most dives were successful and they came up with small fish in their beaks. They could change the position of the fish in their bills as they flew away. Sometimes they would drop it and catch it in mid air. Other individuals would stand near tide pools and wait for a blennie or other small fish to move into the open water. On July 18 the birds were quite active over the reef in a rain storm. Occasionally they would drop, shaking the water from their wing and tail feathers and then recovering, gain altitude.

The period of our stay on the Atoll covered a long nesting season. The nests were placed in the tops of pandanus trees in the whorl of leaves. Young birds were numerous and advertised their presence by a constant squeaking sound somewhat reminiscent of the young of pigeons. One young bird was seen begging and squeaking about an adult and it was fed after grabbing the bill of the adult. Adults collected fragments of palm and pandanus leaves from the ground in the clear areas between palm groves during the whole period of our stay on the atoll. They appeared very awkward as they walked about looking for satisfactory nesting material. Some dived successfully for fragments of leaves floating in the surf as it washed up on the inner beach.

The raucous call notes of these terns, plus those of the smaller species, were never absent, day or night. The noise seemed greater at night, and moon or no moon they were constantly moving about at all hours,

Anous tenuirostris marcusi (Bryan), White-capped Noddy. Also called "te nan."

There were not as common as the larger species, and were easily recognized by the smaller size, blacker plumage and more rapid wing beat. They were seen more frequently fishing over the lagoon than on the seaward side. Otherwise their habits were very similar to those of the larger species.

The first nests definitely belonging to this species were found on Tabuarorae on July 26 in a grove of Pisonia trees. The nests were small for the size of the birds and straddled the larger horizontal branches of the trees about 30 feet from the ground. At least 20 nests were observed there. Where a nest was occupied the bird's beak was visible over one edge and the tail over the other. The area under the trees had a strong ammonia odor and droppings were visible. These trees are also reputed to be the roosting place for the Man-of-War birds. On August 27, another nesting colony of

small Noddies was found, near the center of the North Island, adjacent to the Government Reservation. Here the nests were straddling the petioles of the coconut leaves. There were six to eight nests in a single tree with a maximum of 3 nests on a single petiole. The nests appeared to be much the same as those seen in the Pisonia trees. Birds were on some nests or standing beside them.

Gygis alba, White or Fairy Tern.

This was not a common bird, but occurred widely scattered throughout the atoll, even on the small islets such as Nanntabuariki. We were asked by the Colonial Government to protect this species. The birds moved about in pairs, perched on pandanus or coconut trees, and were most numerous in the central part of the islands. As I approached a pair, they greeted me with loud raucous cries and flew low over my head. No eggs were seen, but a young bird with plumage still tipped with down was brought in by native boys. This is #56 of the collection sent to the U. S. National Museum.

These birds were observed flying in pairs and generally much higher in the air than the other terns.

Eudynamis taitensis (Sparrman), Long-tailed New Zealand Cuckoo.

This bird was seen only on August 22 on the small islet, Nanntabuariki, just north of the large South Island. This islet is covered chiefly with coral gravel. The Scaevola and Guettarda trees are low and scrubby and scattered singly or in small thickets. I flushed this long tailed bird from the base of a Guettarda tree. As it flew away it was attacked by a group of Black Naped Terns who kept diving at it. The Cuckoo paid no attention to the attacking force and flew to the southern tip of the islet and dodged into a thicket. I was successful in finding the bird twice after that. Each time it flew low and swiftly to the opposite end of the island and hid in a thicket. On each flight it was chased by the terns. The bird remained silent. I did not locate the bird on a return trip. This species migrates into this area during the winter of the southern hemisphere.

REPTILES

Lizards and Geckos were common on all the islands of the atoll. Specimens of the species present were collected and have been deposited in the U. S. National Museum in Washington. Dr. Doris Cochran has kindly supplied me with the specific names.

Lepidodactylus lugubris (Dumeril and Bibron), Gecko, "te beru."

This gecko was nocturnal in its habits and was rarely seen during the day. Specimens were found in rotting palm logs in the daytime. They frequently became active in the late afternoon. Once I watched one of these animals on a palm frond, at eye level. The frond was waving gently in the wind and occasionally came close to the frond below it. The Gecko crawled out near the tip of a leaflet and as this leaflet came close to the frond below, the animal jumped to it and then hurried to the mid-rib and out of sight at the base of the leaf.

At dinner time or later in the evening these geckos were seen crawling up the screening on the mess shack, taking advantage of the few insects attracted by the lights. They also crept over the walls of the Residency at night, searching for insects. I assume they were also to be found in the native houses.

On several night collecting trips to Scaevola and Guettarda thickets for insects, I found this Gecko in almost every flower cluster waiting for the night flying insects. On one occasion a Gecko rose on his short legs and stretched out toward a visiting crane-fly, catching it so rapidly that only the subsequent settling back and the "apparent serious business" of swallowing indicated that the prey had been caught. The number of Geckos present at night in a single Scaevola shrub was amazing, considering the apparent scarcity of night-flying insects.

The large Hunstmans spider (Heteropodidae) is one of their natural enemies. A Gecko was caught on the vertical wall of the wash house by one of these spiders and completely covered with silk. When first found the Gecko was still struggling, but became quiet in a very short time. The spider remained with its catch for about a day and a half.

Gehyra oceanica (Lesson), Big tree Gecko

This is the largest lizard on the atoll and one brought in by native boys was about 6 inches long. This specimen was dark brown above and bright yellow on the ventral side except where rough handling had apparently torn off some of the skin.

Only two specimens were secured. I do not know if the animals were rare or overlooked since this species is an inhabitant of trees. Both specimens were brought in by boys.

Emoia cyanurum (Lesson), Skink; "te tikunei."

This was the commonest reptile on the atoll. They were found everywhere, in Scaevola thickets, piles of rubbish, and the litter of the coconut groves. The sparse vegetation of the beach rampart and the smaller islets were favorite places for great numbers of these Skinks. These lizards are very agile and move with a rapid, jerky run. One of the constant sounds heard as you walked over the islands was that made by their scurrying over and through the rubbish to avoid capture or hunting for food. This is a ground inhabiting species but occasionally I saw them dart up the trunk of a coconut or other tree and slip off before they were more than 2 or 3 feet above the soil surface. When alive, their color was bronzy-brown with two longitudinal dorsal stripes, yellow-brown or tan in color. Fifteen specimens were collected.

Part II. Land Invertebrates and Animal Ecology of Onotoa Atoll, Gilbert Islands.

The majority of the Invertebrates collected on Onotoa Atoll belonged to the phylum Arthropoda, principally the class Insecta. Since Onotoa is situated two degrees south of the equator, out of the trade wind belt, rain is not a regular daily occurrence. It is considered a "dry" atoll. The scattered vegetation on the soil surface and areas where the coconut and bread fruit trees are dead, attest to the drought conditions that prevail at intervals.

In contrast to the land Arthropods collected on Arno in the Marshall Islands, where an estimated 500 species were found*, Onotoa at present can boast of no more than approximately 80 species. This number is in agreement with the 96 species reported for Canton Island, another dry island.

In the first part of this paper the invertebrates are reported in their taxonomic groupings. Under the heading of animal ecology, are shown the ecological relationships observed during the short time on the island. Lists of associated species are given at the end grouped under two headings: Habitats and Individual Plants.

PROTOZOA

Protozoans belonging to the genera Paramecium, Frontonia and Difflugia have been recovered in algal material collected in the fresh waters of the babai pits and in the slightly brackish water of pools at the north end of the North Island.

ROTIFERA

In the algal material mentioned above rotifers of two genera were found. One belonging to the order Bdelloidea and the other probably belonging to the genus Monostyla.

NEMATODA

Numbers of Nematode worms were also preserved in algal material taken from babai pits and brackish pools.

MOLLUSCA

The layer of humus and sand under the thickets and under stands of coconut, Pandanus and Messerschmidia trees was sifted for land Gastropods. The large fragments of litter consisting of leaves, old coconut shells and Pandanus seed pods were scraped away and the finer material below was sifted t through a series of nested screens. The material of medium size retained in the screen was bagged and sent to the United States National Museum. The

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*Usinger and LaRivers. Insect Life of Arno. Atoll Research Bulletin 15. April 30, 1953.

following species of snails have been tentatively identified from these soil samples by Dr. Joseph P. E. Morrison:

Opeas gracilis junceus (Gould)

Lamellidea peponum (Gould)

Gastrocopta pedicula (Shuttleworth)

Gastrocopta pedicula nacca (Gould)?

Gastrocopta lyonsiana (Ancey)

One fresh water snail, Melanoides cf naiufouana Mousson was found in a mass of green algae, Rhizoclonium hieroglyphicum Kuetz., collected in a well on the North Island. Dr. Morrison has expressed the belief that this snail was carried with water supplies to Onotoa from some other island. According to his personal communication, this snail closely resembles the large population living on Niaofcu Island.

ARTHROPODA

Crustacea

The coconut crab, a large species adapted to life on land, was brought to us on two occasions. Individuals of this species are rare on the island, probably because the natives utilize them for food. Those brought to us had been captured on the extreme northern end of the atoll.

Hermit crabs, "te makuro", were common and active at night, when their presence was conspicuously evident from the noisy rustling of litter as they moved about in great numbers. These crabs were most frequently found living in turbo shells.

Sow bugs were fairly common throughout the atoll and were collected in rotting logs, under coconut husks, and in the thick humus under old Messerschmidia trees. These animals were most abundant on the area of silty loam soil where a caliche-like hardpan is formed.

A large species of Ostracod was fairly common on algae taken from the babai pits.

Chilopoda

One species of centipede was collected from rotten palm logs and under coconut husks in the area of silty loam soil (caliche). Centipedes constituted a part of a community which included sow bugs and Collembola.

Arachnida

Spiders, called "te nareau" by the natives, were the most abundant terrestrial Arachnids on the island. A large black and yellow species of orb weaver

was ubiquitous; its webs stretched between branches of low shrubs or across the paths in Scaevola, Guettarda and Pandanus thickets. Most of the webs examined were empty, but the great numbers of spiders present suggested that food was probably abundant. One web had the remains of a dragon fly and a moth in it. A smaller, rarer species of orb weaver was also found.

Large crab spiders (Huntsman spider) provisionally identified as belonging to the family Heteropodidae (Sparassidae) occurred quite commonly. They were frequently seen around Pandanus and retreated noisily into the funnel formed by the leaf bases. A specimen was observed feeding on a small gecko on the thatched wall of the shower room. The gecko was completely covered with silk and the spider spent the better part of two days feeding. The longest legs (second pair) on the largest specimen captured had a length of two and one half inches.

Other species of spiders, including a "jumping spider", were collected by sweeping the sparse vegetation, in packing cases, in the litter under trees and on the leaves of trees.

A species of scorpion, Hormurus, was collected in the Residency building in boxes of food and clothing. These were not considered common, for had they been, certainly more specimens would have been brought in by the natives.

Gorged ticks were found on native dogs and were collected from the region back of the ears and around the head.

Insecta

The abundance and variety of insect life usually evident to an entomologist was lacking on this dry atoll. The house fly, one species of dragon fly, and three species of Lepidoptera (two butterflies and one moth) were common. Other insects were generally uncommon and it was necessary to search for them. The clouds of insects so typical of any grass field in eastern United States were never seen.

Odonata and Lepidoptera were collected with an insect net. Diptera, Hymenoptera and some Lepidoptera could be taken from the blossoms of Scaevola and Guettarda. Sweeping the isolated culms of grass produced Cicadellidae, Lygaeidae and a few other small forms belonging to the orders Homoptera, Hemiptera and Diptera. Similarly small spiders were collected. Beating the foliage of trees and shrubs was not very productive although some Diptera and the long horned grasshopper were taken in this manner. Searching under the litter in the coconut groves produced a few sow bugs, centipedes and Collembola. The cocoons of the large ant Odontomachus haematoda (L.) and some adults were found in the same type of habitat. No animals were obtained by means of the Berlese technique.

Fungus beetles and ants were collected in large decaying fungi on dead coconut trees. Termites were found once in an old Pandanus log on the beach rampart. Nymphs of Odonata were found in the water of the babai pits, retting pools and the brackish pools on the north end of the North Island. Dolichopod flies were caught frequently on the leaves of many plants.

Several species of Coleoptera, including the species of Oedemeridae (blister beetle), were taken near lights at night. These, and a lace-wing fly, crane flies and some Noctuid moths were the principal insects so attracted. The absence of large swarms of insects usually found around lights in the temperate zone also indicated a small insect population on the atoll.

The Arachnids, sow bugs, centipedes and insects which were collected on the expedition have been turned over to Dr. J. L. Gressitt of the Bishop Museum for identification and final distribution. All identifications given in this paper are tentative and many were supplied by Dr. Gressitt.

Collembola

Large rafts or colonies of these insects were discovered by Dr. A. H. Banner at low tide in a hollow of an intertidal rock in the lagoon where the tidal amplitude averages two feet. This rocky outcrop is located 300 feet from shore.

A large species of this Order was collected under dead coconut husks in the area of the caliche. Collembolans, sow bugs and centipedes formed an association under this type of litter on the atoll.

Thysanura

Several specimens of Thysanura were taken in a moist area under the bark of a rotting stump of Messerschmidia.

Orthoptera

Cockroaches, "te babatuannanu", were the most common species of this order. The species Cutilia soror (Brunner) were present in abundance under the rubbish that covered the camp site and were exposed as the site was cleared. Individuals continued to appear in luggage and stores throughout the summer, although the majority of them moved away when the area was disturbed. This species is common from Hawaii to the Ellice Islands (Zimmerman, 1948*). At night a number of specimens were taken on the under surface of young palm fronds at one to two feet above the surface of the soil. Evania appendigaster (L.), a Hymenopteran, is parasitic on the eggs of this cockroach. An Evanid fly was fairly common; identification has not yet been made but the great abundance of both insects may be significant. Two other species of cockroaches were collected. One of these, tentatively identified as Pycnoscelis surinamensis (L.), was winged and collected under litter in a coconut grove. These last mentioned species were not common.

A medium sized green Tettigonid grasshopper tentatively identified as the genus Phisis was brought in frequently by the children. The tibia of the first and second pairs of legs were covered with long spines on both the outer and inner surfaces. Since the children were paid for these specimens with candy, they could not be coaxed to divulge the habitat of the species. Search by the author revealed two specimens, resting, with legs stretched out at full length, on the under surface of leaves of Ficus tinctoria. It cannot be said with

*Zimmerman, E. C. 1948. Insects of Hawaii. V. 2. Univ. of Hawaii Press.

certainty whether this was their specific habitat or just one of many places they occurred. Sweeping the grass Lepturus did not produce any specimens of this species.

A small pale yellow cricket was collected near lights around the camp. Their thin weak songs were heard all about at night. The song consists of a short ascending note and a longer descending one, usually repeated about ten times between intervals.

Isoptera

Decaying logs and branches of trees were examined for termites but were located only once in a Pandanus log at the top of the beach rampart on the sea side of the North Island. Judging from its position, it is possible that this log had floated here from some neighboring atoll.

Neuroptera

A single species belonging to the family Chrysopidae was collected near lights. The general body color is yellow green, and the eyes are a distinct black. Specimens were taken in June, July and August.

Odonata

One of the most thrilling sights particularly on calm mornings was the occurrence of huge swarms of dragon flies hawking low over the grass tops or higher up around the tree tops. At such times the house flies were particularly numerous and annoying. It is assumed that the dragon flies were preying upon them. This same swarming of dragon flies was noticed at Majuro in the Marshall Islands and at Bikati in the northern Gilbert Islands. The common species of dragon fly was distributed generally over the atoll, except on the small island of Nanntabuariki. There are no pools or wells present on this island, but it is possible that dragon flies would reach it in passing back and forth from the larger islands. Large swarms were found around the brackish fish ponds on the north end of the large North Island as well as in the region of the brackish pools on the North Island and the South Island of Aiaki. They were also present in the region where babai pits were located. Nymphs were found in the fresh water of babai pits and in the brackish water pools mentioned above. At least three species were collected. A large green and blue species resembling Anax junius of North America, a medium sized reddish brown species (the most common), and a small species of which the males are bright red. This last was the least common.

A single species of damsel fly was found in the babai pit areas and in the area of the brackish pools. These did not venture far from the water.

Hemiptera

True bugs were rare. A species of Lygaeidae of the genus Nyseus was taken by sweeping the isolated clumps of the grass Lepturus growing in the coconut groves. A single reddish brown Pentatomidae was found on the foliage of Guettarda. In the tide pools left in the beach rock on the seaward side of the

islands after the exceptionally high spring tides of August, water striders of the family Gerridae, genus Halobates were collected.

Homoptera

Cicadellidae were captured by sweeping the isolated clumps of the grass Lepturus growing in the coconut groves. A Fulgorid related to the sugar cane leaf hopper was collected in the camp area. Plant lice were present on Sida fallax, but were not common. Other plants seemed to be quite free of aphids. Scale insects were common on many of the older Messerschmidia trees.

Coleoptera

Nine families of beetles were represented in the collections from the atoll, with the possibility of a tenth family after the material is properly identified.

Staphylinidae, which were attracted to lights, were also collected on rotting Pandanus fruit left on the ground.

The most abundant beetle was an Oedemeridae of the genus Sessinia. When this beetle was crushed on the skin it caused a blister. These insects were rather abundant and a pest to the human population. The Islanders gathered "toddy" from the coconut trees by allowing the sap from the cut end of a flower bud to drip into an empty coconut shell or bottle. This dripping sap was attractive to these beetles and they frequently drowned in it. A native drinking "toddy", which contains one of these insects will experience violent pain, accompanied by hemorrhage in the urinary tract. One affected by this ailment was known to treat himself by drinking immense quantities of water. These beetles commonly came to lights.

Cleridae was represented by the "copra bug" of the genus Necrobia. These small metallic green beetles were fairly common and were attracted to lights.

A few specimens of the Elateridae, Conoderus pallipes, were collected. One specimen was taken at Scaevola flowers at night.

Beetles of the family Dermestidae were collected on drying skins of rats and birds. Nitidulidae beetles were present on rotting Pandanus fruit and larvae and adults were collected from chocolate bars stored with provisions.

Large old bracket fungus growths on dead coconut palms provide a home for Erotylidae beetles, in company with ants.

Lady-bird beetles, Coccinellidae were taken on Scaevola Morinda citrifolia and Messerschmidia. A large tan colored beetle taken in the mission house on Tabuaeran Island was tentatively identified as a Cerambycidae.

A small species of weevil was taken twice, once on rotting Pandanus fruit and another time near a light.

Lepidoptera

Three species of butterflies were collected, two Nymphalidae and one Hesperidae. The large Nymphalid, Hypolimnas bolina, was the most common and was found all over the atoll. Its food plant Sida fallax was common in the clearings of the palm groves, along the beach ramparts and on coral gravel areas. All stages in the life cycle were found. The eggs were deposited on the underside of Sida leaves. Black hairy larvae were so common in some cases as to defoliate the plants. Chrysalids kept in cages completed their dormancy in 7 to 10 days. Adults were observed at night with wings folded on the underside of Scaevola, coconut and Pandanus leaves. Children caught these large butterflies and tied a string of coconut leaf fiber around their thorax and played with them in much the manner of an American child playing with a pinwheel.

The smaller brown Nymphalid, probably a Precis villida (Fabr.), was also widespread and very common. Its food plant was probably Messerschmidia as smooth caterpillars typical of the genus, with longitudinal black and white stripes, were abundant on this tree.

A single specimen of Hesperidae was collected on Callophyllum inophyllum. If this tree were the food plant of the species, its rarity could be accounted for by the few trees on the island.

The moth fauna of the atoll is more varied, with a greater number of species, representing at this writing the following families: Arctiidae, Noctuidae, Sphingidae and Pyralididae.

The most common moth was a day flying Arctiidae of the genus Utetheisa. This moth was first seen on Kwadak, an island of the Kwajalein Atoll. It was subsequently found on Majuro Atoll, the island of Bikati on Makin Atoll and the island of Betio at Tarawa, all stopping places made on the trip to Onotoa. In most cases it was captured and observed wherever Messerschmidia or Scaevola grew. The black hairy caterpillars, the apparent larvae, were abundant on Scaevola. The moth was common on the North Island, but rare on the southern islands of the atoll.

At least 5 species of moths of the family Noctuidae were collected. The largest and most common species was tentatively identified as Achaea janata. The under wings are banded with black and white stripes superficially resembling a small Catocala. It occurred in swarms on Pemphis wherever that shrub grew. This moth was also taken near lights. At least four other species typical of the family were collected around lights and await identification.

A day flying, clear winged moth of the family Sphingidae was collected from blossoms of Scaevola and Guettarda. It was never abundant, but usually one or two were seen each day. Sphingid caterpillars were taken on Morinda citrifolia, which is evidently the food plant of this species. A Sphingid pupa case was brought in by a native, but unfortunately was destroyed by ants before it matured. A copulating pair of these moths was captured near a light at the Residency on August 2. These moths were also tied with strings and used as living toys by the native children.

A small green winged moth, with pure white body and legs, of the family Pyralididae, was taken on and around Guettarda on the North Island and Aonteuma. It was among the insects drawn to lights.

Several other small moths, almost micro-lepidoptera were captured. One with wings the color of gun metal was on Sida fallax. The other species came to lights.

Diptera

The first Dipteran seen and the one always present was the ubiquitous house fly. Great swarms were present and were especially annoying on calm days. They infested the open sores on the natives and it was quite evident that cuts and abrasions on our own limbs were soon infected by these flies, making it necessary to keep all sores and cuts covered until they were completely healed. The native population was extremely careful about refuse, but the open pits for garbage, the pens in which hogs were kept, and the habit of defecating on the reef and beaches, afford ample breeding areas for these flies.

Flies tentatively identified as Sarcophagids were observed and caught on bags containing decaying mollusk shells set aside for cleaning. These flies also swarmed in our own garbage pit, in spite of the fact that refuse was covered as quickly as possible with soil. At least two species were collected. A blue bodied fly, a Calliphoridae of the genus Chrysomyia, was taken on the flowers of Messerschmidia.

Dolichopod flies were quite common and were seen frequently on the foliage of Scaevola and on other plants. They were collected on most of the islands of the atoll.

Anthomyiidae were collected on unripe Pandanus fruits. These flies were quite sluggish but difficult to capture around the fruits.

A Syrphid fly was taken around Messerschmidia along the beach rampart of the North Island. The markings are typical of this group.

Mosquitoes were never very abundant. They were noticed on several occasions at night in the Maneabas (Community meeting houses) and were extremely abundant in the village of Aiaki on the South Island. At other times they were found personally annoying only when collecting on the babai pits where they breed. Wigglers were found several times in old coconut shells that had become filled with water. The extreme drought conditions on the atoll for the last year and a half may explain the reason for relative freedom from the pests.

A medium sized black crane fly, probably a Tipulidae was taken by sweeping the grass. It was also the chief pest around the lights at night, many of them, dead or drying, were constantly falling on the table where we worked.

Chironomid larvae were found in abundance on algae collected in the babai pits and brackish pools.

A large flat black fly with a buzzing flight was captured near a light. Later another specimen was taken on litter on the beach rampart and a third on the drying skin of a Great Crested Tern. These were members of the family Hippoboscidiae.

A single specimen of an orange bodied fly of questionable identity was taken near a light.

Hymenoptera

The most conspicuous Hymenopteran on the island was the large jawed black ant identified as Odontomachus haematoda. It was seen on all the islands of the atoll in sandy areas, including the beach rampart. Colonies of a few individuals, protecting a few brown cocoons, were found under old Pandanus and coconut logs.

At least two other species of ants were collected, but these were not common. A minute red species lives in fungus growing on dead coconut trees. A nest of the other species containing eggs, larva, pupa and winged adults was uncovered below the hard surface of the "caliche", near the northern end of the North Island. A procession of this species was also attracted by spilled sugar in the storage tent where a few individuals were collected. Pandanus fruit rotting on the ground attracted ants, as well as other insects.

A large tan colored species of Ichneumon fly was found frequently flying around the Scaevola thickets, but its prey was not located. It is recorded on all the islands of the atoll.

An evaniid wasp, probably Evania appendigaster (L.), was common. It is recorded from all of the islands of the atoll. Reference was previously made in this report to the fact that this insect is probably parasitic on the eggs of the abundant cockroach, Cutilia soror.

A small black vespid wasp identified provisionally as belonging to the Odynerinae is common around the flowers of Scaevola and Guettarda. Two of these insects were taken in the hollow twigs of Scaevola, although no nests were found when other dead hollow twigs were examined. These wasps are common throughout the atoll.

A large bronze green Sphecid wasp, Ampulex sp., was observed making nexts and depositing eggs in the holes of the reed furniture of the Residency and in the holes and crevices left in the native lime stone walls of the Residency and mission houses. Mud was employed in the construction of the cells.

A single species of bee, Megachilidae, was found on the north end of the North Island and on Aonteuma. The work of these leaf cutting bees was first noticed on leaves of Pisonia grandis, while trying to secure specimens of the latter for the herbarium collection. The leaves were so badly cut, that entire ones were not available. Small semicircular portions about 3/4 of an inch in diameter had been cut from the margins of the leaves. Damage of this kind was later seen on Morinda citrifolia. Specimens of the bees were collected around Pisonia, Morinda and Pemphis.

ANIMAL ECOLOGY

Coconut Groves

The major portion of the land area on the atoll is covered with an overstory of coconut groves and an understory of Pandanus, Scaevola and Guettarda. The ground in the groves is strewn with fallen leaves and other litter, with scattered forbs and grass growing through this litter. These groves were usually silent and devoid of animal life. Noddy Terns were sometimes present in the palms and a few Fairy Terns on Pandanus, but both birds seemed to prefer the open areas. Near the villages, flocks of chickens were encountered wandering about in search of food. The ground skink (Emoia)was the most conspicuous animal throughout these groves and was frequently heard scuttling away over the litter.

Removal of the litter disclosed a large population of the cockroach Cutilia soror and colonies of the large ant Odontomachus haematoda . Sifting the fine litter and top layer of soil revealed sow bugs and the minute Gastropod snails belonging to the genera Opeas, Lamellidea and Gastrocopta.

Clearings

Along the center of the two large islands and scattered irregularly at other places sunny clearing occurred containing only scattered palm, Pandanus and Messerschmidia trees, and a more dense shrub and herbaceous cover. These areas supported a large population of both species of Noddy Terns and the Fairy Tern. In these clearings the calls of the adult birds and the food call of the young were heard day and night. Here also adult Noddies frequently swooped down to earth and waddling awkwardly gathered pieces of shredded coconut leaves for nesting material. The Golden Plover was flushed from these clearings several times. Clouds of dragon flies were usually cruising at tree level, particularly on calm days when the house flies seemed to be most annoying. The two common butterflies, Hypolimnas and Precis flew above the herbs. Sida fallax, frequently the dominant herb in these areas was the host plant for Hypolimnas and carried a large population of eggs and larvae.

Skinks were as common in the litter here as in the groves. Ants and cockroaches were present under the litter and the large Huntsman Spider was captured around the clumps of Pandanus.

Area of Brackish Pools (Caliche-like hardpan)

On the North Island east of the village of Taneang and on the South Island east of Aiaki village are two rather similar areas, differing from the typical coconut groves. The trees were far apart and Pemphis formed the understory around a series of small brackish water ponds. The soil is the consistency of nearly dry putty and Dr. Preston E. Cloud, Jr. has designated it as a "caliche-like hardpan". Dragon flies were abundant and nymphs were numerous in the algae filled pools. The fauna of the brackish pools is dealt with in another portion of this report. A few damsel flies were observed resting on the foliage of Pemphis bordering some of the pools. Butterflies, the Achaea moth and leaf cutting bees were present in addition to the dragon flies. Orb weaving spiders had constructed webs between shrubs.

Skinks ran through the rubbish piles. During the day geckos were found hiding in rotting logs. Under decaying coconut shells and leaves was found an association of sow bugs, Collembola and centipedes. Colonies of a small species of ant seemed to find the soil of the right consistency for their nests. A large species of land crab was seen to occupy burrows in these areas.

Scaevola Thickets

Throughout the atoll, in neglected coconut groves, in clearings and along the sea side beach rampart there were thickets of Scaevola. Since these shrubs were in continuous bloom during our stay on the island, many species of insects were found visiting the blossoms. The list of insect visitors is given in a following section. Many leaves of the plants were attached by leaf miners. Dolichopod flies were frequently seen walking over the leaf surfaces.

The ground skink was observed climbing clumsily into the flower clusters during the day. The orb webs constructed by two species of spiders were numerous and were suspended in gaps between branches. The population of spiders, geckos and skinks present appeared too great for the quantity of insects observed at any one time. However, food must be sufficient to support the population. On only a few occasions were insect remains observed in the spider webs.

Observations of these flowering thickets at night revealed considerable activity. Geckos were present in almost every flower cluster feeding on crane flies and other night flying insects. Crickets were heard all through these thickets. The two common butterflies, Precis and Hypolimnas, were found sleeping on the underside of the leaves. The large Huntsman spider was also active here at night. The constant rustling of the litter under the shrubs indicated the great nocturnal activity of the numerous hermit crabs. On rare occasions rats were observed running from thicket to thicket.

Shrub Growth on Sand Flats

A shrub cover of scattered Scaevola, Guettarda, Pemphis, Sophora, Terminalia and Suriana maritima was growing on sand flats at points where the islands narrowed and were separated by the shallow inlets. These areas were bright from the reflection of the sunlight on the white sand and very hot on calm days. The southern tip of the North Island, the southern end of Aiaki or South Island and the adjoining point of Tabuarorae were the largest of these areas. Noddy Terns were observed with young in this area on Tabuarorae. Reef Herons were flushed from the openings between shrubs. Dragon flies, Precis butterflies and Sphingid moths were the common insects here. The Noctuid moth Achaea was very common on Pemphis.

Coral Gravel Areas

On extremely exposed shores on the seaward side of the atoll were large areas of coral gravel. The few scattered plants offered little cover, explaining the near absence of animal life on these gravel fields. An occasional skink was seen. The butterfly Hypolimnas was present where the scattered Sida plants grew. At the north end of the North Island where the gravel fields bordered the large enclosed fish pond, swarms of dragon flies filled the air above the Pemphis growing along the shore of the pond. However, the dragon flies did not wander far out over the barren gravel.

The Black Naped Terns and Whimbrels seemed to prefer this gravel area on the seaward side of Abanekeneke as headquarters. On every trip to this island we found and disturbed these birds on the gravel flats.

Pisonia Grove

One small grove of Pisonia trees was growing on the edge of a coral gravel area on Aonteuma. The leaves of these trees had been so badly damaged by the leaf cutting bees, that it was impossible to find perfect specimens of the foliage for a herbarium specimen.

A large grove of tall mature Pisonia trees on Tabuarorae Isle supported a large nesting population of the small species of Noddy Tern. Native tradition named the community house or Maneaba of this southernmost village the "Maneaba of the large trees where the birds roost". The Man-of-War birds were reported using these trees frequently as roosting spots. The accumulation of droppings and the odor under the trees indicated a large concentration of birds.

ANIMALS ASSOCIATED WITH HABITATS

Land Communities

A. Coconut Groves

Noddy terns-two species
Fairy terns
Chickens

Skink (Emoia)

Orb weaving spiders

Sow bugs-under the litter

Cockroaches-under the litter
Ant-Odontomachus haemotoda -soil surface and litter

Gastropod snails-three genera in litter

B. Clearings (Widely scattered trees)

Noddy terns-large population of both species
Fairy terns
Golden Plover-rare

Skink (Emoia)

Orb weaving spider
Huntsman spider

B. Clearings, cont'd.:

Cockroaches-in litter
Dragon flies
House flies
Butterflies (*Hypolimnas* and *Precis*)
Ants-*Odontomachus haematoda*

C. Area of Brackish Pools (Caliche-like hardpan)

Gecko
Skink (*Emoia*)

Sow bugs-under the litter
Land crabs-burrows

Centipedes-under litter

Collembola-under litter
Dragon flies-common Nymphs in pools
Damsel flies
Butterflies (*Hypolimnas* and *Precis*)-common
Achaea moth-on *Pemphis*
Mosquitoes-South Island
Leaf cutting bees-around *Pemphis*
Ants-small species-nest in soil

D. *Scaevola* Thickets

Rats-rare

Gecko-feeding at night
Skink (*Emoia*)

Hermit crabs-in litter beneath shrubs

Orb weaving spider-two species

Crickets-heard at night
Butterflies-*Hypolimnas* at flowers
Precis adult at flowers, larva on foliage
Moths-*Utetheisa*-flowers and foliage
Sphingid-flowers
Noctuids-resting on leaves
Click beetles
Lady Bird beetles
Crane flies-flowers at night
Ichneumon fly
Wasp-Odynerinae

E. Shrub Growth on Sand Flats

Noddy terns
Reef herons

E. Shrub Growth on Sand Flats, cont'd.:

Precis butterfly
Sphingid moth
Achaea moth-on Pemphis
Dragon flies

F. Coral Gravel Area

Black Naped tern
Whimbrel
Long tailed New Zealand cuckoo-in thickets

Skink (Emoia)

Orb weaving spider

Dragon flies
Sphingid moth
Butterflies (Hypolimnas and Precis)
House flies
Syrphid flies
Dolichopod flies-on foliage
Leaf cutting bees

G. Litter, Rubbish, Rotting Logs (In groves and under isolated trees)

Rats-rare

Noddy terns-for nesting material

Gecko
Skink (Emoia)

Sow bugs
Hermit crabs

Huntsman spider

Centipede-under coconut husk

Collembola-under coconut husk
Thysanura-under bark of dead Messerschmidia tree
Cockroaches-three species
Termites-rare, log on rampart
Beetle larvae-in log on rampart
Ants-two species
Mosquitoes-larva in water filled coconut shells

Gastropods
Opeas gracilis junceus (Gould)
Lamellidea peponum (Gould)
Gastrocopta pedicula (Shuttleworth)
Gastrocopta pedicula nacca (Gould)?
Gastrocopta lyonsiana (Ancey)

H. Buildings and Huts

Rats-nest with young

Gecko

Spiders-in packing cases and crannies
Huntsman spider
Scorpion-rare

Cockroach-Cutilia soror
House flies-by day
Mosquitoes-at night
Crane flies-near light
Moths-various species to light
Long horned beetle-identification uncertain
Coconut blister beetles (Oedemeridae)
Wasps-two species

I. Insects Taken at Light

Cricket
Lace winged fly (Chrysopidae)
Large dragon fly-Anax sp.
Blister beetles-Oedemeridae
Long Horned beetle (Ceresium)
Rove beetle-Staphylinidae
Copra bug-Cleridae
Click beetles-Elateridae
Noctuid moths-several species including Achaea
Small moths-almost micro-lepidoptera
Pyralididae moth
Sphingid moth
Crane flies
Mosquitoes
Orange bodied fly-family unknown
Hippoboscidiae

J. Rotting fruit on ground

Beetles-Nitidulidae
Staphylinidae
Cleridae
Tan colored beetle?
Weevil
Ants-small species

ANIMALS ASSOCIATED WITH SPECIFIC PLANTS

A. Coconut palm

Noddy terns-two nesting species
Reef heron-nesting

A. Coconut palm, cont'd.:

Gecko-on foliage

Cockroaches-on underside of leaves of small plants at night
Butterflies-on underside of leaves at night
Flies-on underside of leaves at night
Blister beetles-around toddy
Fungus beetles-in fungus on living and dead trees
Ants-in fungus on dead trees

B. Messerschmidia

Sow bugs-in litter beneath

Moths-Utetheisa-adults and larvae
Noctuids at flowers
Syrphid flies
Calliphorid flies-Chrysomyia at flowers
Scale insects on bark of twigs
Lady bird beetles

C. Pandanus

Noddy terns-young and adults of both species
Fairy terns-young and adults

Gecko

Huntsman spider
Orb weaving spiders

Cockroaches-on underside of leaves at night
Butterflies-on underside of leaves at night
Flies-Anthomyiidae-around green fruit
-other species on underside of leaves at night
Rove beetles-Staphylinidae on rotting fruit
Nitidulidae beetles-rotting fruit
Weevil-rotting fruit

D. Sida fallax

Butterfly-Hypolimnas-eggs, larvae, chrysalids and adults
Small tan colored moth
Pyralididae moth
Plant lice

E. Morinda citrifolia

Sphingid moth-larvae on foliage
Lady bird beetles
Ichneumon flies
Leaf cutting bees-attacking foliage

F. Guettarda speciosa

Pentatomid-stink bug
Pyralididae moth
Sphingid moth-at flowers
Odynerinae wasp-at flowers

G. Pisonia grandis

Noddy tern-small species nesting
Man-of-war bird-reported roosting

Leaf cutting bees-leaves badly damaged

H. Pemphis acidula

Moth-Achaea janata-very common
Damsel flies-resting on foliage
Leaf cutting bees

Note: Usinger and LaRivers report Pemphis on Arno as seemingly a barren tree as far as insect life is concerned. They report the Achaea moth, so common on Pemphis at Onotoa, as associated with Cordia, a plant not present on this atoll.*

FRESH WATER HABITAT

Surface water on the atoll was found in the babai pits used to grow the native "taro", in brackish ponds scattered at several places on the atoll and in wells. Algae samples were taken from these situations and preserved. During preliminary examination of these samples a number of invertebrates have been observed. While they have not been positively identified, mention should be made of them since they are obviously part of the food chain ending in the Odonata or the Reef herons.

Protozoa

Paramecium sp.
Frontonia sp.
Difflugia sp.

Rotifera

Monostyla sp.
Species of Order: Bdelloidea

Nematodes

Mollusca

Melanoides cf. niaforiana Mousson (With algae in well)
(Ident. by J. P. E. Morrison)

Crustacea

Ostracods
Crabs

*Usinger and LaRivers. Insect Life of Arno. Atoll Research Bulletin No. 15. April 30, 1953.

Insecta

Chironomid larvae
Mosquito larvae
Nymphs of dragon flies-3 species
Nymphs of damsel fly-one species

Aves

Reef heron

MARINE HABITATS

Seaward Reef

When the reef was covered by the tide on stormy days the Noddy Terns could be seen flying back and forth over the reef, capturing food. At other times they fished beyond the algal ridge. The Fairy Terns even on stormy days, generally fed beyond the ridge and only occasionally were noticed over the reef itself.

As the tide ebbed, the shore birds and reef herons advanced out over the exposed reef, investigating tide pools and the drying turf of algae.

The water strider, Halobates was found in the tide pools on the reef after the high tides of August.

Seaward Beach and Beach Rampart

The stretch of beach from the Scaevola thickets along the rampart to the high tide line was bare of vegetation. The shore birds were active along this beach at high tide. The Turnstones were most active just at the water's edge, rapidly flicking over pebbles, bits of rubbish, dried sea weed and bits of shells looking for prey. Each section of the beach and reef had its small flock of shore birds. The number of flocks and the number of individuals in the flocks increased during August.

The Reef Herons seemed to have rather definite territories along the beach and reef. By keeping certain peculiarly mottled individuals under observation the approximate size of their beach and reef territories could be roughly estimated. A beach and reef front territory at the cemetery on the south end of the North Island measuring approximately 1000 yards was occupied by a white heron having a slate gray head and a gray stripe down the middle of its back. Another mottled individual occupied a similar territory north of the camp site. Individual herons trespassing into these territories were attacked and forced out by the original occupant.

The skink (Emoia) was observed in the thickets on the rampart and made short journeys down the slope of the upper beach.

Gray rock crabs (Grapsus grapsus L.) were very common on the outcroppings of rock along the beach. At night the ghost crabs (Ocypode sp.) were common. One was observed feeding on a dead jellyfish, stuffing the jelly into its mouth as fast as it could, oblivious to the light from a flashlight. The beach and

rampart was also alive at night with large and small species of hermit crabs. The large species living in old turbo shells seemed to come down to the beach at this time from the thickets along the ramparts.

Since Scaevola was the dominant plant along the rampart, the insects here were those native to the thickets of this shrub as was previously mentioned. Dragon flies frequently swarmed above the beaches. Similar swarms were seen on the islands of Bikati, northern Gilberts, during the trip to Onotoa.

Lagoon

Tattlers, Golden Plovers and Reef Herons were the common birds along the lagoon shore. The small species of Noddy Tern seemed to prefer fishing in the lagoon to the seaward reef and was more frequent here than was the larger species. The Black Naped Terns were also lagoon feeders and were rarely absent from the shallow northern end.

Swarms of dragon flies were frequently seen along the lagoon shore. Collembola were collected from the water in a hollow of the rock outcropping, 300 feet from shore, near the village of Taneang by Dr. A. H. Banner. The tidal fluctuations of this spot were about two feet.

MARINE COMMUNITIES

A. Seaward Reef

Wandering tattler
Ruddy turnstone
Golden plover
Whimbrel
Noddy tern-larger species more frequently
Fairy tern-rarely
Crested tern
Reef heron

Water Strider-Halobates

B. Beach and Beach Rampart

Wandering tattler
Ruddy turnstone
Golden plover
Reef heron

Skink (Emoia)-rampart and upper beach

Rock crab-Grapsus grapsus
Ghost crab-Ocypode sp.
Hermit crabs-several species

Dragon flies-swarming over beach
Ant-Odontomachus haematoda -upper beach and rampart

C. Lagoon

Wandering tattler-along shore
Golden plover-along shore
Reef heron-along shore and shallows
Black naped tern-over lagoon, fishing
Noddy tern-small species usually, fishing over lagoon

Dragon flies-swarming along shore
Collembola-tide pools in rock

Fiddler crabs-sand flats

ATOLL RESEARCH BULLETIN

No. 29

A Summary of Information on Rose Atoll

by

M.-H. Sachet

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A summary of information on Rose Atoll

by
Marie-Hélène Sachet

Rose Atoll, the easternmost of the Samoa Islands, is one of the smallest atolls known and is of special interest, because it has hardly been influenced by man. Its situation not too far from the settled islands of the group, the fact that it is generally easy to enter the lagoon and land on the islets, and various other circumstances have made it one of the better known uninhabited atolls. The literature concerning it has been brought together by Setchell (1924) and by Bryan (1942). This paper is not intended to replace these contributions but to summarize all available information on land aspects of the atoll. It necessarily repeats much information contained in these earlier compilations but may thus be helpful to those students of atolls to whom these are not easily available. In addition to published accounts, it includes notes based on letters of Mr. E. H. Bryan, Jr. and on conversations with Dr. L. P. Schultz and data obtained from their photographs and unpublished records. Their valuable help is gratefully acknowledged.

Geography

Rose Atoll is located between 14°31' and 14°34' S and between 168°08' and 168°10 W. It is a very small atoll, roughly square in outline and about 1 3/4 miles from north to south and 2 miles from east to west. Just west of the north point, or corner of the square, is the only channel into the lagoon. The channel is 100-150 feet wide and of variously reported depth: 6 fathoms or more (Rantzau in Graeffe, 1873), 30 or 40 feet (Anon., 1953) with records of 6 to 9 feet, or 6 feet or more that are probably erroneous or refer to the part of the channel that is choked with coral: Bryan (1942) reported the channel partly blocked with coral heads on the west side. The lagoon is about 2000 yards across its greatest width, and its depth is variously estimated as 6 to 12 fathoms (Wilkes, 1845), not more than 8 fathoms (Mayor, 1924) or up to 50 feet (Bryan, 1942). The floor of the lagoon is sandy, and generally free of living corals (Couthouy, 1942, p. 138). But some corals do grow in it. Wilkes described one such formation: "like a submerged tree, thirty feet in diameter over its top [it] was found in the center of the lagoon rising to the level of low water and having all around it a depth of six fathoms." This may be part of the two coral patches mentioned by Rantzau (Graeffe, 1873) as occurring in the southwest corner of the lagoon and indicated on his and later maps.

The reef is remarkably uniform in width, about 500 yards everywhere, with a very flat surface, most of which is under water even at low tide, though some areas emerge as smooth platforms about a foot above low tide. There is very little loose material on the reef. It supports only two islets. Sand Islet, to the north, near the entrance to the lagoon, is a bank of sand and broken reef material, devoid of vegetation and about 5 feet above sea level. Although the charts are not entirely reliable, there is some indication that the islet has been

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larger (see discussion of Rantzau's chart, (pp. 4-5).
Sand Islet is quite possibly variable in area, especially as no plants are present that are capable of colonizing and fixing its soil. In 1938 its dimensions were estimated as 200 yards in length and 50 yards in width (Bryan, 1942). It lies on the lagoon side and has a wide expanse of reef on its seaward side.

At the eastern corner of the square is Rose Island, which is larger than Sand Islet. Mayor, in 1920, gave the length as 240 yards along a north to northeast direction and the width as 200 yards. Bryan, in 1938, estimated the island 350 yards long and 250 yards wide. Schultz (1943, p. 3) says that in 1939 it seemed to be building up on the northwest and being eroded on the south end. This agrees with some notes by Mayor and Bryan. Rose Islet has a greater elevation than Sand Islet, reaching 11 feet above high tide a little inland of the southeast corner (Mayor, 1924, p. 74). It is higher in the south than at the northern end and, like Sand Islet, it is located on the lagoon half of the reef.

History

Rose Atoll was discovered on October 21, 1819, from the ships l'Uranie and la Physicienne, and was named Rose Island by the commander of the expedition, Louis de Freycinet "for a person extremely dear to me." The ships did not enter the lagoon or come very close to the island. However, Freycinet described the island as observed from the sea, and Duperrey drew a chart that is included in the atlas of the expedition reports. In his volume on navigation and hydrography (1826, p. 85), Freycinet gave information on the weather, on the animals observed off the atoll, on the longitude, and on the latitude estimated at noon. He described his discovery (1826, p. 250) marveling at the fact that the atoll had not been observed and charted earlier. He mentioned only Rose Islet, but he said of it:

> "Its height generally mediocre, is greater in the SW; the land gradually slopes down toward the NE where it merges with the sand of the shore.
>
> "Although very small, this island is well wooded, which gives it a very pleasant look of freshness. Various sea birds seem to be the only inhabitants of this lonely place; we particularly noticed frigate birds, boobies, tropic-birds, noddies, and terns [apparently two small species]. Among the trees, there are no coconut trees nor any other kind of palms.
>
> "The whole island, as we have said, is surrounded by a bank just below water level, grossly triangular, of mixed sand and madrepores; it is bristling with small black rocks, not very much raised above its surface, and all of about the same height. One of the angles of the bank is to the SW, another to the E, and the third to the N: its dimensions are 3 miles [nautical] from N to S, and a little less from E to W. The sea breaks much all around, and the surge can be felt from one or two cable lengths at sea: we followed its eastern part at a distance of one

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and a half mile[s], without seeing bottom under us.

"When one stands to the N of Rose Island, it shows a semi-circular shape; seen from the E it looks like a 'coin de mire' [is wedge-shaped] with its higher part looking to the south. To the NE, and very close [to the islet?] a little black rock, a regular cone, rises above all the rocky heads just mentioned."

This literal translation shows that Freycinet observed the islet and reef exactly, which makes it all the more difficult to understand some aspects of Duperrey's chart, namely, the two areas that Setchell interpreted as two additional sandy islets. Although Freycinet did not mention any sandy "islet", his drawing of the landfall, presumably made from about east to southeast, showed on either side of the wooded islet some little black rocks and a broad mound. These may be sand banks and correspond to the patches of the chart. Freycinet's description of the islet is detailed enough for us to believe that the trees may have formed two groves, a large one to the southwest and a tiny one to the northeast, which apparently does not exist any more. The northeast grove either joined the other one or was destroyed by a change in the shape of the islet. Freycinet described Rose again later in his historical account of the voyage.

The Russian expedition of the Predpriatie (Enterprise), commanded by O. de Kotzebue, passed a little coral island on April 2, 1824, and named it Kordinkoff (Kotzebue, 1830, p. 256), later to realize that it was the same as Rose. Kotzebue's sketch of the atoll is not much better than Duperrey's, although it shows a closed lagoon.

On September 23, 1838, Dumont d'Urville, on another French expedition, passed Rose Island following the reef at a distance of less than a [nautical] mile and gave a brief description of it (1842, pp. 91-92):

"Rose Island is but a pile of sand about 200 m. in diameter, covered with a grove of verdure very fresh looking and pleasant.

"Passing about 600 m. to the north of the reef edge, we saw in the reef a break about 100 m. wide, leading into the lagoon where the water seems rather deep, and which ought to be able to offer shelter to ships as small as ours."

The French expeditions were scientific in purpose, and their instructions placed much emphasis on obtaining physical, nautical, and meteorological information. The discovery and surveying of new lands was recommended also, but these lands were especially worth investigating if they could bring new people and their customs, new plants, new animals, to the notice of Science. The fact that low islands present danger and difficulty in landing, especially with a sailing vessel, as well as their recognized paucity in scientific novelties, resulted in a general avoidance of atolls by most early expeditions, including the French.

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The U. S. Exploring Expedition was different in scope and aims, and without neglecting scientific discovery, visited many of these atolls, reputedly all alike, for the purpose of charting them. It was much larger than any of the previous expeditions both in ships and in naval and scientific personnel. In spite of its vessels and the unending arguing, prosecuting and fantastic mishandling of the results which followed it, the expedition was generally remarkably successful, and, although some of the information has never been published, it brought back vast amounts of data, charts, scientific collections, and drawings. It was the first "Atoll Program", and after surveying many of the Tuamotus, one of the ships, the Vincennes arrived at Rose Atoll, on October 7, 1839. A part of the day was spent in observations, and Wilkes (1845, p. 64) in the narrative of the voyage gave an account of them, but the best description published, and the only one of an eyewitness, is that of Pickering (1876, pp. 235-236):

> "14. ROSE CORAL-ISLAND. As the Vincennes drew near, the supposed rock proved to be a dense clump of trees upon a small coral-island; 'in S. Lat. 14°18' and W. long. 168°05', and about eighty miles' from the nearest rocky island of the Samoan Group. Rose coral-island, though hardly 'two miles' in diameter, was found to contain a lagoon; having a large outlet deep enough to admit a ship, and 'six fathoms' inside, except at the centre of the lagoon, where a column of coral-rock rises to within 'three feet' of the surface. The tide rising 'about five feet', most of the island is submerged at highwater; but the outline continues distinguishable by the line of surf, with here and there a projecting massive coral-block; at all times, we found much water beating over from the windward, and running in streams into the lagoon, and afterwards in a strong current through the outlet.
>
> .....
>
> "Two banks on the rim were never overflowed by the tide; one of them devoid of vegetable growth; the other, containing the above-mentioned dense grove of trees, found to be three or four acres in extent."

Dana (1849, p. 78, 308) also discussed Rose Atoll, but unfortunately he did not see it, as he was traveling in another of the ships. Couthouy, however, was still on the Vincennes (he was going to abandon the Expedition shortly, in Samoa), and presumably landed on Rose. Parts of his account (1842) seem different from what was reported by Wilkes, Pickering, and Dana, and his account has been termed "somewhat fanciful" (Setchell, 1924): but he did give some information on the entrance and lagoon. He noted (p. 99) that the entrance is to leeward, as is often the case on atolls, and water pours out of it at ebb tide "so as to resemble a mill race."

The next recorded visit was that of Captain Rantzau (Graeffe, 1873, p. 32), who visited the atoll at various times while a German firm was trying to establish a fishing station there. He transmitted some valuable information to Graeffe and drew a sketch of the atoll, on which Sand Islet

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is represented as large and extending far into the lagoon and Rose Islet as covering the whole width of the reef and supporting a house and trees. During these times coconut trees were planted and reported to do well and to bear fruit. The island was settled for a while by an Englishman and a few natives. Later one native alone remained with his family, and then the island was finally restored to its loneliness. Rantzau's sketch, together with excerpts from Graeffe's text, was reproduced in the first volume of the Hydrographische Mittheilungen (later Annalen der Hydrographie...) p. 64, 1873. His outline of the reef may have been based on some earlier chart, but his sketch was apparently used at later dates by the Hydrographic Offices of England and the United States.

In 1899, after much tension and political difficulty, Eastern Samoa became an American territory. The first governor, B. F. Tilley, visited Rose Atoll on July 10, 1900, hoisted the American flag "with appropriate ceremonies," and planted coconuts. In January 1920, Governor W. J. Terhune visited the Manu'a district, and on January 12 landed on Rose Atoll, erected a sign to warn trespassers, and planted a variety of fruit trees, including coconuts. His stop at Rose was reported in the monthly government newspaper O Le Fa'atonu, in the issue for February 1920 (Dumstrey, 1920). In June 1920, he returned there and was accompanied by the marine biologist A. G. Mayor who was working in Samoa. The July issue of O Le Fa'atonu gave a short but informative account of the visit and mentioned the value of the information collected by the distinguished scientist. More coconuts were planted, including two on Sand Islet. The invitation extended by Governor Terhune to A. G. Mayor resulted in valuable observations that are the most important body of information on Rose Atoll and are described in other parts of this paper.

There were yearly governor's visits to the atoll after this and more plantings of coconuts. In 1922, Governor Pollock found that Governor Terhune's coconuts had disappeared, so he planted some more. He also collected soil samples for Lipman.

Wray Harris now conchologist at the B. P. Bishop Museum, made at least two visits to Rose in 1937 and 1938 and collected mollusks and a few plants.

In 1938 the U. S. Coast Guard cutter Taney visited the Equatorial Islands and landed a party of scientists on Rose Atoll on August 4, for an hour. E. H. Bryan wrote accounts of his observations (1939 and 1942, pp. 91-93), and much of our knowledge of Rose Atoll is derived from them. W. Donaggho (1953, p. 68), assistant to G. C. Munro, wrote some notes on the birds observed.

In 1939 the U. S. S. Bushnell made a survey of islands in the central Pacific, and Dr. L. P. Schultz, of the U. S. National Museum, spent 11 days collecting fish around Rose Atoll and in the lagoon (June 11-21).

On February 14, 1941, Rose Atoll was made a Naval Defense Sea Area by an Executive Order of President F. D. Roosevelt.

This order was rescinded by Executive Order 10,341 signed by President Truman on April 8, 1952. Earlier (July 1, 1951) the Samoan

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Islands had come under the jurisdiction of the Office of Territories in the Department of the Interior. In February 1953 a fishing survey was conducted near Rose Atoll, and some information on the island was published in the Weekly News Bulletin on February 21, 1953. Excerpts from this bulletin were received through the kindness of Mr. Emil Sady, chief of the Pacific Division, Office of Territories. This is the latest information available on Rose, and it brings up to date our knowledge of this little atoll.

Meteorology

There are no meteorological records whatsoever from Rose Atoll. Even the visitors whose accounts are used here gave almost no information on the weather at the time of their stays, except for the weather at sea described by Freycinet. The only source of data that gives an idea of meteorologic conditions in the region is the Weather summary for Naval Air Pilot, H. O. 272 of the U. S. Hydrographic Office, which is used throughout this section, without further acknowledgment. It offers information that can be used in getting an idea of weather and climate at Rose Island and is compiled from ships' observations, mapped and tabulated for 5-degree ocean areas, together with general trends as expressed by isobar or isotherm charts. The island nearest to Rose Atoll from which are available data that cannot be collected by ships' observations (such as temperature variation and total rainfall) is Tutuila. But this is a high island, and its weather station at Pago Pago is dominated by a mountain called the "Rainmaker", because it precipitates moisture from every cloud passing over it. The atoll nearest to Rose with some weather data is Puka-Puka (Danger Island). It is in the same 5-degree square as Rose but in the northeast corner ($10^{\circ}53'S$, $165^{\circ}54'$ W.) The records available since 1929 are summarized in a note by the New Zealand Meteorological Office (Seelye, 1943), and in the Great Britain Pacific Islands Pilot (v. 3, 1946). Both of these publications also offer some information on weather and climate at Aitutaki, the other weather station nearest to Rose Atoll, although much to the southeast. This is a high island (460 feet) on an atoll-like reef. The observations are made on the west side of the main island ($18^{\circ}52'30"W.$) at an altitude of 10 feet. Rather than use data from the high Samoan Islands or Niue, those from Puka-Puka and Aitutaki are occasionally mentioned, because they can at least give an idea of the order of magnitude of conditions on Rose Atoll.

Atmospheric pressure: The 1008-millibar isobar for January passes just north of Rose Atoll and just south of Puka-Puka; the 1012-millibar isobar for July passes near the location of Rose, whereas the 1010-millibar isobar for July passes close to Puka-Puka. (Great Britain Pacific Islands Pilot, v. 2, pp. 18-19). These figures probably express the range of variation at Rose Atoll, except, of course, for depressions accompanying possible hurricanes.

Tropical cyclones and hurricanes: No cyclones and hurricanes are reported from Rose Atoll, but among the Samoa Islands, years may pass without a destructive storm, though two or three cyclones have been known to occur in a single year, with January and March as months of highest frequency. The most famous hurricane in Samoan history is that of March 13 to 23, 1899, which, occurring at a moment of great international tension, kept everyone so busy that political issues became

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secondary and were solved more amicably than they might otherwise have been. The track of this hurricane (Chart 23, H.O. 272) does not pass near Rose Atoll, nor do any other tracks of the few cyclones plotted on this chart. East of Rose Atoll, hurricanes have been known to occur and cause much damage, at Puka-Puka, Nassau, and especially at Suwarov, but they are rare.

Prevailing winds at sea: Rose Island lies in the region where the northeasterly trade winds penetrate the south latitudes: In the 5-degree square just north and west of that of Rose (5° to 10° S., 170° to 175° W.), surrounding the Union group, 29 percent of the annual winds are from the northeast, 32 percent from the east, and only 13 percent from the southeast. At about the 10° S. the southeast trade winds definitely become more frequent; and in 10° to 15° S, 165° to 170° W. (Rose Atoll square) southeast winds are recorded as 25 percent of the annual winds, northeast trades as 17 percent, and east winds, the most frequent, as 34 percent (see table p. 9).

Ocean gales, squalls and thunderstorms: Rose Atoll lies in an area where both gales and squalls are rather common, being reported in 14 percent of the ships' weather observations. Thunderstorms are reported in 4 percent of the ships' observations. All the figures for gales, squalls, and thunderstorms are much less for the 5-degree square of Rose Atoll than for the next one west, where the high Samoan Islands are situated.

Sea temperature: Rose Atoll lies in a region between the two 82° F isotherms for sea temperature (north and south of the Equator) for February (southern summer), and the 80° F isotherm for sea temperature (Southern Hemisphere) for August passes just north of Rose (Great Britain Pacific Islands Pilot, v. 2, pp. 18-19). These figures probably express the range of yearly variation of sea temperature at Rose. At Puka-Puka the variation is reported as from 81° to 83° F (Seeley, 1943).

Air temperature: There are no figures at all for air temperature at Rose Island or the ocean around it. At Puka-Puka the mean for the year is 82.2° F, with very slight variation from month to month (83.1° for May, warmest month; 81.8° F for January, coolest month). The averages of the annual extremes are 93° F and 71° F, and the absolute extremes are 97° F and 70° F. At Aitutaki the Southern Hemisphere seasons are well marked; the warmest months are January and February (81.0° F mean temperature), and the coolest is August (75.4° F). The yearly mean is 78.2° F. At Rose Island the southern seasons are probably slightly felt, whereas Puka-Puka still has Northern Hemisphere seasons. Rose probably has a rather even yearly temperature, of about 81° F, the extremes not reaching much above 90° F or below 70° F.

Clouds and visibility: Table p.8 is made from Charts 13 to 17 of H.O. 272, for the 5-degree square of Rose Atoll. The total of ships' weather observations for this square is 760 for the period 1879-1933.

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Feb. 78	May 49	July 74	Oct. 63	Dec. 63	
					Figures express percent of observations recording lower type clouds.*
3.4	5.1	4.4	9.5	5.4	Percent of observations with exceptional visibility.
1.7	1.3	1.5	0.0	1.8	Percent of observations with haze.
0.0	0.0	0.0	0.0	0.0	Percent of observations with fog.

* Lower type clouds are apparently the trade wind cumulus and various rain clouds.

Relative humidity: At Puka-Puka the mean relative humidity for the year is 79 percent, with a variation of 2 percent above and below for the individual months (morning observations); the mean dew point ranges from 74° F in July to 78° F in April, the average being 76.3° F (Seelye). It may be assumed that figures for Rose Atoll would be similar.

Rainfall: The evenness of rainfall is an important factor on atolls, in making the amount of precipitation effective. The rain water percolates immediately through the extremely porous material forming the islands, so that the amount of rain that corresponds to extremely arid conditions on an atoll may mean much moister ones on large islands or continents. On Puka-Puka the rainfall is usually heavy, the average for 1930-1942 being 117.57 inches a year, the totals ranging from 85.46 (in 1938) to 155.13 (in 1931). There is a marked rainy season from November to March. The average number of rainy days (with 0.10 inch or more rain) is 170 days per year. This is rather low. At Aitutaki the yearly average is 77.57 inches in 92 days, and there is a wet season from December to March (Seelye, 1943). Rose Atoll probably has a similar rainfall, although the number of rainy days may be greater.

High seas: It may be of interest to mention that on Puka-Puka in February 1935 a hurricane that affected Rarotonga brought rather high seas (Seelye, 1943). The seas rose on the 8th, and canoes left under trees 200 yards from the usual low-tide mark were nearly washed away. Conditions were worse on the 9th and 10th, but the sea went down rapidly the following day. This phenomenon might have affected Rose Atoll also.

Geology*

The reef of Rose Atoll is almost entirely made up of Lithothamnion rock as are the boulders scattered on it. The surface of the atoll rim, where awash at low tide, is covered by vigorous growths of Porolithon that form connected pink patches or -- west of the lagoon entrance -- ridges 6 inches high and 6 inches to several feet wide. The ridges,

* The geology and soils sections were prepared with much assistance from F. R. Fosberg and utilize unpublished data from his investigations in the northern Marshalls in 1952.

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Ocean area S10 165. Position: Latitude 10° - 15°S, Longitude 165° - 170°W.
Greenwich noon observations. Years covered 1883-1933.

Month	Number of observations surveyed	Wind: Mean velocity (knots)	Wind: Percentages of observations from — N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Weather: Percentages of observations recording — Haze	Mist	Fog	Drizzle	Rain	Light Squalls	Showers	Thunder-storms	Heavy squalls	Gales (force 8 or over	Exceptional visibility	Mean cloud amount (0-10)
January	45	11.1	8	27	16	21	6	5	7	5	5	0	0	2	0	15	20	9	2	0	8	4	4.6
February	59	8.9	11	30	19	5	2	11	4	17	1	2	0	0	2	8	8	10	5	0	0	3	4.6
March	57	8.4	14	19	29	19	5	0	5	7	2	2	0	0	0	18	16	7	4	0	2	5	5.5
April	66	5.7	5	19	31	15	7	2	0	6	15	2	0	0	0	5	2	3	3	0	0	3	3.8
May	78	9.7	5	19	44	27	1	1	0	0	3	1	0	0	0	8	12	6	3	0	0	5	4.2
June	76	11.1	5	8	54	25	2	1	1	1	3	1	0	0	0	4	12	10	3	1	3	0	3.6
July	68	11.6	5	8	50	29	6	0	0	1	1	1	1	0	0	9	12	12	1	1	0	4	4.8
August	64	11.1	0	10	40	43	3	2	0	2	0	2	0	2	2	5	11	11	0	0	0	8	5.5
September	66	12.0	3	20	34	41	2	0	0	0	0	0	0	0	0	0	15	11	3	2	2	0	4.7
October	63	8.0	7	13	36	29	2	2	4	4	3	0	0	0	0	2	9	14	3	3	0	9	4.2
November	62	8.0	10	10	35	22	5	7	4	7	0	3	0	0	0	5	11	8	5	0	0	8	4.9
December	56	6.8	21	17	20	21	0	7	0	10	4	2	0	0	0	6	4	5	11	0	0	5	4.8
Mean		9.4	8	17	34	25	3	3	2	5	3	1	*	*	*	7	11	9	4	1	1	5	4.6
Total	760																						

From H.O. 272, p. 62. Compiled by the U.S.Weather Bureau

* Less than 0.5 percent.

which are separated by channels, are occupied by other algae. The slopes of the reef are not different in their algal constituents from the flat top, except for the presence of some stunted Acropora and Pocillopora (corals) "at the extreme edges of the atoll rim fronting the lagoon or the sea." The algal ridge at the edge of the reef is very weakly developed, as also are surge channels (Schultz, conversation 1953). Freycinet mentioned small black rocks, all of about the same height, and the U. S. Exploring Expedition found then to be limestone boulders. Mayor gave them much attention and wrote (1924, p. 75):

> "Hundreds of large blocks of limestone lie scattered over the flat, wave-washed rim of Rose Atoll. These loose boulders are quite uniformly about 5.5 feet high, and only when tilted are they any higher. In addition to these boulders there are a few others which are mushroom-shaped and still remain attached to the floor of the atoll-rim, of which indeed they form an integral part. One of the most remarkable of these mushroom-rocks lies to the eastward of Rose Islet, and is supported upon so slender a pedicel that it would seem as if the next storm must cause it to topple over. In many places over the flat, wave-washed floor of the atoll-rim one finds remnants of pedicels which once supported 'mushrooms'. In addition, some of the boulders have become secondarily cemented to the floor of the flat by the growth of Lithothamnium around their bases. The largest boulder we observed lay loosely upon the reef-flat east of Rose Islet and was somewhat tilted by being jammed against another rock. It was 12 feet 5 inches long, 8 feet wide, and 7 feet 6 inches high, and as its specific gravity was 2.3 it apparently weighs 46 tons."

He concluded that the boulders showed that sea level must have been at one time 6 or 8 feet higher than now and that the scattered detached boulders were mushrooms that had been completely undercut. He reported that the boulders were made up of the same algae and had generally the same chemical composition as the solid reef platform, with the same high percentage of magnesium attributable to Porolithon.

Among these boulders, the Exploring Expedition found some scattered blocks of volcanic stone. They are mentioned by Wilkes, Dana, and Couthouy and also by Pickering, who says (1876, p. 235):

> "For the first time on a coral-island, the mineral kingdom was represented; several blocks of vesicular lava being met with by our party; in all instances resting upon the coral-shelf, not imbedded. Two or three of these blocks were seen by myself, the largest weighing perhaps twenty pounds. From the mineral composition, they had evidently been derived from some volcanic island; and there seemed no means of transportation, unless entangled in driftwood. This actually takes place at the Tarawan coral-islands; where Mr. Hale found a native name for 'basaltic stones in the roots of trees drifted to those shores'."

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Mayor failed to find these rocks among the coral blocks and supposed that the members of the Exploring Expedition had mistaken blackened limestone for basalt. The matter rested until 1939, when Schultz again found them. He only mentions (1940, p. 48) collecting lava but (conversation, 1953) observed many volcanic blocks, a dozen or more up to the size of a man's head, scattered on the reef. His specimens were brought back to the U. S. National Museum and were found to be compact olivine basalt. They are being studied further by Gilbert Corwin, who says the rocks are olivine basalts, such as are typical of Pacific islands. Schultz supposed that they might have been thrown up from the sides of the island with the niggerheads.

For an idea of the geology of the two bits of land on this reef, we must rely almost entirely on Mayor's account.

Sand Islet is "a mere accumulation of fragments of Lithothamnium shells, and broken coral .... only about 5 feet above high tide level." The loose and unstable nature of such debris lying on a flat reef surface makes entirely probable the changes in size and shape of the islet indicated in the different accounts and maps. There is no suggestion anywhere that any of this material is consolidated or cemented to the reef.

Rose Islet, on the other hand, seems to be mainly a mass of such debris that has been consolidated into a "coquina" or reef-conglomerate such as is a common feature of other atolls. Probably the word "coquina" is improperly used here, as the material is not primarily composed of shells. Mayor's description of this follows (1924, p. 74):

> "The tree-covered rocky center of the islet is composed of a coquina consisting chiefly of wave-worn fragments of lithothamnium and also rare and occasional fragments of broken coral, such as Favites, Porites, Symphallia, Pocillopora, and still more rarely Acropora. Embedded in it are many wave-worn half-valves of Tridacna and gasteropod shells, and spines of Echini such as Cidaris were found, as was also the much corroded ulna and part of the skull of a small cetacean about the size of a blackfish, the latter being embedded in the coquina about 8 feet above high-tide level. A large amount of organic matter, dark brown in color and derived from the decomposed roots of the Pisonia trees, permeates this coquina to a depth of several feet. All of the fossils found embedded in the coquina are forms now living on the reef-flat, which have simply been tossed on shore by the waves."

The height of this conglomerate above the reef surface is rather remarkable for such a small islet. Mayor says, "On the southeast side of Rose Islet the sand-beach is reduced to from 1 to 5 feet in width at low tide, and cliffs of coquina from 5 to 8 feet high front the sea .... A few feet inland this rocky ledge rises to a height of about 11 feet above high-tide level."

Schultz (1943, p.3) says that on this southeast side the island apparently is being eroded away. Here, again, on the southeast shore, is some beach-rock, said by Mayor to be more recent than the "rocky matrix of the islet." Schultz (1943, p. 3) adds, "To the east of the island for a few hundred feet are loose slabs of coral-shell conglomerate rock left on the reef, which may have at one time formed part of the island." These must be slabs of beach-rock as shown by photographs.

On the northwest side the islet is reported by Schultz to be building up by accumulation of coral debris (incorrectly called breccia by Mayor). Here the beach is much wider. On the surface of the conglomerate where it is covered by the Pisonia grove there seems to be little accumulation of loose material (Schultz simply says that the conglomerate is "overlaid by coral-shell gravel"). No boulder ridges, dunes, or "ramparts" have been described.

Soils

The surface of Sand Islet and the bare north part of Rose Islet are apparently of unaltered or scarcely altered limestone debris, largely of algal origin. This debris is similar to what is found on bare or newly formed parts of most atolls, except that the proportion of algal material is unusually high here.

The soil within the Pisonia grove is very different and is the subject of an extensive study by Lipman and Shelley (1924). A good description of the profile does not exist, but from Mayor's casual remarks and Lipman and Shelley's descriptions of the materials they analyzed, a profile can be roughly reconstructed as follows:

Top layer -- (Mayor) "a rich chocolate-colored humus which is of considerable depth near the southern end of the grove."

Intermediate layer -- (Lipman and Shelley) "a loose porous mass, very light in weight," (Mayor) "dark brown in color .... to a depth of several feet."

Bedrock -- (Lipman and Shelley) "a compact, fine-textured, almost pure calcium carbonate which shows no vital structure. It is pure white, fairly soft ..." (but see Mayor's description of the coquina, which is the same material, p. 11).

Lipman and Shelley regard the intermediate layer as being an intermediate product in the decomposition of the bedrock, to form, with the addition of much humus, the surface layer of "fine-textured, mellow, organic soil." They had only a small bit of soil adhering to a partly decomposed rock, this rock, and some of the bedrock to examine and work with. Their interpretation of their analytical results is completely dependent upon this conception of the origin of the profile, and if more recent studies in other atolls (Fosberg, in press; Hatheway, 1953) are reliable, their interpretation is erroneous, the situations seeming more

or less comparable. Stone (1951, p. 10) regards Lipman and Shelley's conclusions as entirely vitiated by the presence of basalt fragments on the reef.

Lipman and Shelley's analyses are as follows (p. 208):

	Rose Islet soil	Intermediate product	Lithothamnium rock	Water soluble constituents		
				Rose Islet soil		Intermediate product
	p.ct.	p.ct.	p.ct.		p.p.m.	p.p.m.
H_2O at 100°C	5.12	2.49	0.40	Total soluble salts	26,000	11,600
Loss on ignition	22.84	31.09	46.22	Na_2CO_3	1,837	2,171
SiO_2	.18	.20	.16	Na_2SO_4	4,414	2,435
Al_2O_3	16.72	9.20	.46	NaCl	14,391	1,755
Fe_2O_3	.40	.48	.....			
P_2O_5	20.94	14.60	.57			
CaO	29.26	35.78	44.01			
MgO	1.75	3.34	7.46			
SO_3	1.14	.87	.61			
Na_2	1.38	1.39	.35			
K_2O	.23	.23	.15			
TOTAL	99.97	99.66	100.40			

The striking facts about these analyses are the increasingly high percentages of Al, P, S, Na, and K (from bedrock to soil), compared with decreasing percentages of Ca and Mg and very little change in Si, also the greater moisture-holding capacity of the organic soil and the "intermediate product."

Lipman and Shelley's explanation of the high aluminum content and low silica content is ingenious. They explain, "The aluminum silicate in the original rock undergoes decomposition through reaction with ammonia, formed from the decomposition of the soil organic matter or of the bird droppings on the islet. Such a reaction would be followed by the leaching out of the ammonium silicate formed and, while allowing of the accumulation of alumina in the soil, would prevent accumulation of silica there." This would necessitate a reduction of 36 times in the weight of soil decomposed to yield this amount of alumina.

The two authors interpret the increased of sodium, potassium and sulfur as results of the great adsorptive capacity of the soil, differential leaching, and increment from spray.

The astonishingly high phosphate content of the soil and the rather high content of the "intermediate product," they regard as resulting from

simple accumulation of the phosphate of the original rock, without even taking into account the bird droppings usually considered the source of such phosphates. The correspondence of the figures with those for aluminum would suggest this conclusion, but then the problem would arise of what had actually become of the phosphorus in the droppings of the large bird population that is found on the island.

The picture, in light of investigations, incomplete as yet, in the Marshalls, supported by a survey of the literature, appears to be actually quite different. Generally, under Pisonia forest, a layer of pure humus, corresponding to Mayor's description and acid in reaction (pH 4.5 to 6), accumulates. Usually these forests are inhabited by large numbers of birds, as on Rose Islet. Their droppings (normally pH 6) are acidified by the humus as they are washed down through the humus layer, and the finely divided calcium phosphate is dissolved. When it reaches the sand and rock beneath, it becomes alkaline and therefore insoluble, precipitating out and cementing the loose calcareous material together. The acid solution tends to dissolve out the calcium carbonate and permits it to be replaced by calcium phosphates. Thus a cemented layer or hardpan is formed immediately beneath the humus layer.

This process is not at all similar to the one suggested by Lipman and Shelley. It would not account for the enormous concentration of aluminum, nor the relatively low loss on ignition. It is clear, from the two authors' description of their soil sample "containing many undecomposed particles of the original lithothamnium rock," and the fact that their sample was material adhering to the surface of the partially decomposed rock, that they did not have a typical sample of the pure humus as described by Mayor. The ignition loss would likely have been much higher if the sample had been representative. The high aluminum content may well have been the result of contamination by decomposed pumice pebbles, common enough on atolls, or even from the basalt. How the silicon was lost if so, is not clear, except that it tends to leach out under tropical conditions.

There is a record of subsequent samples being collected for Lipman by Governor Pollock, but though they were studied for soil micro-organisms, no more chemical analyses were reported. Further studies to ascertain whether this high Al content is a general feature or only a localized one would be desirable.

One other fact revealed by Lipman's investigations is the unusually high concentration of water soluble salts in the soil (see table of analyses, p. 13). The authors mention, "If our analyses are to be considered as even approximately correct, the Pisonia tree is to be regarded as one of the most salt-tolerant plants of which we have record at present." They point out that the toxic effects of the salts may be somewhat mitigated by the high content of organic matter present but consider that the tolerance is still remarkable. This concentration may well be of significance in connection with the extremely small land flora of the atoll and possibly with the lack of success of the coconuts planted there repeatedly.

In a bacteriological study of the soil samples collected by Governor Pollock, Lipman and Taylor (1924) found that the numbers of organisms were enormously higher in the humus-rich soil in the Pisonia

forest, much lower in the soil where Boerhavia and Portulaca were growing, and extremely low where there was no vegetation. This is exactly what would have been expected and does not require further comment.

The authors found, also, that both nitrite and nitrate producing bacteria are present in all the soils, and that their nitrifying activity is more or less proportional to the amount of organic matter in the soils. What was probably Azotobacter was found, but it was concluded that such organisms "do not find conditions propitious for their rapid development in competition with other forms which occur there."

Land Flora

The land flora of Rose Atoll was first described by Pickering (1876, p. 236):

> "The whole flora of the island consisted of but two species of plants: one of them, as will be perceived, additional:
>
> Portulaca (No. 1). Normal; multicaul and prostrate, having the habit of P. oleracea, but much larger flowers; petals five, yellow. Growing in a scattered manner on top of the beach, and in all instances outside the grove.
> (Calpidia ovatifolia?); bis (No. 1 Paumotu coral-islands). Constituting the grove; some of the trees being fifty feet high, with the trunk four feet or more in diameter. Additional anomalies of growth were here observed: as two proximate upright branches anastomosing ladder-like at intervals; and several instances of upward-tending branches, as in the trees seen in the distance on Serle and other coral-islands. The timber proved on examination to be brittle and to all appearance worthless."

Pickering's observation of the two plants had been reported earlier by Dana (1849, p. 309). The plants were discussed and identified as Pisonia grandis R. Br. and Portulaca lutea Sol. by Setchell (1924) who was studying Mayor's specimens. Mayor gave the second enumeration of the flora, and found one more plant, Boerhavia tetrandra Forst., growing on the rough limestone surface of the north part of the islet, with Portulaca.

In 1938, Bryan recorded no native plants other than those three, which is a remarkable fact. It would be interesting to know when Boerhavia took hold. It would probably not have been missed by Pickering, who was familiar with it and had found it on several of the Tuamotus. No account mentions plants other than the grove of trees, between the time of the U. S. Exploring Expedition's visit and Mayor's visit.

In the U. S. National Herbarium there are no specimens from Rose Atoll collected by Pickering. He may not have made any collections. There are several sheets of Pisonia grandis from later collections, however:

Bryan 1382, Aug. 4, 1938; Wray Harris 287, April 1938; Schultz 26 and 27, June 11, 1939. There is also a sheet of Portulaca lutea, Schultz 25.

In the B. P. Bishop Museum (information kindly supplied by E. H. Bryan, Jr., curator) there are sheets of the three phanerogams: Pisonia grandis: Setchell 50 (collected by A. G. Mayor, June 6, 1920); Wray Harris 274 and 287, April 21, 1938; Bryan 1382, Aug. 4, 1938. Boerhavia tetrandra: Setchell 51 (collected by A. G. Mayor, June 6, 1920); Wray Harris 303, April 21, 1938, and 304, November 30, 1937; Bryan 1384, Aug. 4, 1938. Portulaca lutea: Setchell 52 (collected by A. G. Mayor), June 6, 1920); Wray Harris 301 A, Nov. 30, 1937; Bryan 1383, Aug. 4, 1938.

The latest addition to the flora, due to human interference, is that of the coconut palm. The story of the Rose Atoll coconut palms is quite intriguing; the palms flourished at the time of Rantzau's visits, but had disappeared by 1900. Of those planted by Rantzau, one remained in 1920, sterile, probably as suggested by Dumstrey, because it was choked by the Pisonia trees. The nuts planted by Terhune in January 1920 were growing in June, but had all disappeared by 1922, when Pollock planted some new ones. Bryan in 1938 found about 20 palms, 8 large and a dozen small. Schultz (unpublished notes) observed seven large trees and two small ones, besides several recent plantings now 1 to 3 feet high. The tall palms were bearing nuts, and photos show that some of the fallen nuts may have been sprouting. By 1953 the total number was reduced to 12 and these were bearing heavily, and it is hoped that no more were planted, and that Rose Atoll will have a chance to increase its flora by natural means only. Why the palms have failed to survive and multiply, when some did grow into adult trees from planted nuts, is hard to explain. Perhaps the coconut palms were destroyed by a typhoon between 1873 and 1900, whereas the Pisonia grove was seemingly unaffected; this is possible since Pisonia trees are practically indestructible, new trunks springing up from fallen ones (see below, Vegetation). Most of the plantings of nuts probably failed very early. Another possible explanation has been suggested on page 14; it is possible that the high concentration of water-soluble salts in the soil prevents coconut seedlings from developing. The rainfall of Rose Atoll, if estimated at 77 to 110 inches a year, is not very heavy; and it may be irregular. In any case, the minute islet may not be sufficient in area to permit the formation of a fresh-water lens, and the palms may suffer from physiologic drought. There may be also too great an amount of sea spray for coconut seedlings to do well. In this connection, it may be remarked that the three native plants are very hardy ones, often found alone or with a few other such halophytic species, on the most destitute atolls. Schultz (unpublished notes) also records plantings of bananas, papayas, and a few other plants, and indeed a very small banana plant is discernible on one of his photographs. But it is not known whether these plants have persisted.

There is only one record of a macroscopic land cryptogam, a lichen, which Bryan collected on the trunks of the Pisonia trees, and which has not been identified as yet (Bryan 1385, in Bishop Museum). In the study of the soil flora, Lipman and Taylor isolated 19 bacterial colonies of which they gave descriptions (pp. 213-214). Most of them were actinomycetes, one or two could clearly be recognized as other than actinomycetes, and one was a mold. The presence in the soil of nitrifying bacteria and Azotobacter has been mentioned in the section on soils.

Vegetation

According to all available reports, Sand Islet is completely destitute of vegetation. Governor Terhune planted two coconuts on it, but they did not grow.

The fresh green grove of trees is the most conspicuous feature of the vegetation of Rose Islet, giving it from afar the appearance of a low rounded hill, for which it has often been mistaken. Freycinet seemed to indicate the presence of two separate groves (see History); Wilkes wrote, "The islet is entirely covered by the clump of trees." Pickering said of Portulaca plants that they grew on the top of the beach, which might indicate that indeed the grove covered most of the island surface. Later, Mayor estimated that the trees occupied one half of the land area, and in 1953 this was reported as only one third. It is difficult to decide whether the grove has decreased or the island grown larger. The latter is possible, especially since its estimated dimensions are reported larger in 1938 than 1920, and it seemed in 1939 to be increasing on the northwest side (see Geography). It is more unlikely that the Pisonia grove should become much smaller, unless parts were removed by a hurricane.

The forest is made up entirely of large trees of Pisonia grandis with no undergrowth at all. Pickering, Mayor, and others emphasize the fact that the other plants do not grow at all under the trees. This is, furthermore, quite normal in luxuriant Pisonia groves on atolls. When Mayor visited Rose, one coconut tree, probably planted by Governor Tilley, grew among the Pisonia. Rantzau's sketch map of the island showed mixed coconuts and other trees, but this may not have been meant to express the exact condition, as the Pisonia would probably shade out the growing coconut seedlings. Pure Pisonia forest occurs on various atolls in the Pacific, for instance on some islets of the northern Marshalls, and especially on Vostok Island, which must be very like Rose. The trees have many twisted stems with creamy white bark and large light-green leaves. Pisonias can attain enormous sizes, and those on Rose Atoll were fifty feet in 1839, 80 in 1920 and estimated at 85 feet in 1953. The largest are on the southern part of the islet, and, in 1920, one had a girth of 25'7" at 3 feet (Mayor, p.73). Pisonia can form sprouts from practically any part of the tree, roots, branches, stubs, and fallen trunks, forming luxuriant tangles of stems and branches. This forest on Rose Islet must be a magnificent sight. Two good photos of it by Mayor accompany Setchell's paper, and Bryan published two of his own that show well the rounded contour of the grove.

Along the northeast edge of this grove are the coconut palms. They have been discussed in the description of the flora.

The whole north part of the islet is free of trees, and the surface of broken reef material supports Boerhavia and Portulaca. One of Mayor's photos (in Setchell, 1924) shows well this tangle of low plants. The Boerhavia plants have a thick woody root crown, with creeping stems up to 3 feet long. The Portulaca form little bushy succulent herbs up to 2 feet high, with erect, much branched stems, fleshy but firm. Besides the north part of the island, these two plants seem to be scattered on

the strand along the Pisonia grove, at least on the lagoon side (Mayor, p. 74).

Except for the lichen collected by Bryan, no mention is made on macroscopic cryptogams in any of the available accounts. Possibly other cryptogams occur on Rose, and a search might discover them. The black limestone boulders strewn over the reef doubtless owe their color to microscopic blue-green algae.

Fauna

There have been a few collections of land animals on Rose Atoll, by Mayor, by members of the 1938 and 1939 surveys (see History), and by others. The specimens have been added to museum collections but have not been mentioned in the literature.

Birds are the most conspicuous animals on the atoll. Freycinet (see History) mentioned frigate birds, boobies, noddies, tropic birds, and terns. At sea (p. 85) he also observed curlews on the day of the discovery of the atoll. Wilkes observed at least four kinds:

> "Birds were seen flying over the island, and on landing we found them in great numbers and very tame. The frigate-birds, and boobies (sula), whose nest had before been observed on low bushes, were here found on the tops of trees fifty feet high. The noddies laid their eggs on the parts of the island destitute of vegetation. Tern were in great numbers; their breeding-place was in a thicket on the weather side of the island, or that which was exposed to the wind and sea, and was remarkable from the regularity with which the eggs were placed, about three feet apart, without any nest, and, with but few exceptions, out of many thousands, each egg lay separately. The colour of the eggs is a dirty white, mottled with brown. The noise made by these birds when disturbed was almost deafening; but on making a loud sound, such as the firing of a gun, their cries would cease for a moment or two, producing a singular stillness."

Graeffe only said that a great many birds, especially species of Sterna or sea-swallows, nested in the trees.

Mayor wrote:

> "Several hundred boobies (Sula), most of which had half-grown young, were nesting on the coral breccia of Rose Islet ..., while others had constructed nests of sticks high among the branches of the Pisonia trees. A few boatswain-birds with eggs were also nesting in the trees, and several nearly grown young sooty terns visited the island at night. Frigate-birds were hovering over the island, but none were nesting. Wilkes states that the noddies and sooty terns were nesting on

Rose Islet on October 7, 1839, and these species were still nesting when Governor Terhune visited the island on January 10, 1920."

In 1938 (Donaggho, 1953, p. 68) frigate birds were flying above, brown boobies were nesting, and red-footed boobies were sitting in the trees, as did the fairy terns. Munro (1949, p. 50) said that there were numbers of these lovely white birds, and he hoped that they did not too often get gummed with the sticky fruit of Pisonia. Bryan (1942, p. 92) also reported some wandering tattlers; and reef herons, one blue, one white.

Schultz in 1939 (1940, p. 48) observed that in the Pisonia trees were nesting boobies and frigate birds and "underneath, on the ground sooty terns were nesting." This had been mentioned by Donaggho and seems rather unusual. In his unpublished notes Schultz also recorded yellow-billed [blue-faced] boobies, nesting on the ground with their white and downy young, and brown boobies. He vividly described the enormous numbers of birds, their incessant clatter, the terrific stench of guano, which falls "like rain all day and night" from the trees. His collections of bird skins are preserved in the U. S. National Museum:

USNM 358134	Sula leucogaster plotus (Forst.)	brown booby
USNM 358138	Demiegretta sacra (Gmel.)	reef heron
USNM 358149	Anous stolidus pileatus (Scop.)	common noddy
USNM 358155	Heteroscelus incanus (Gmel.)	wandering tattler

Summary of other birds recorded:

Sula sula rubripes Gould	red-footed booby
Sula dactylatra personata Gould (Schultz photo)	blue-faced booby
Fregatta minor (Gmel.) (?) (probably this, but could be F. ariel)	frigate bird
Phaeton lepturus (Daudin) (probably this, as Mayor says it nests in trees)	white-tailed tropic bird
Sterna fuscata L.	sooty tern
Gygis alba (Sparrm.)	fairy tern
Numenius tahitiensis (Gmel.) (Freycinet, probably this species)	curlew

The 1953 survey only mentions the presence of birds. It is rather interesting to observe the fact that the same species have visited Rose Atoll for more than 100 years and were found in the same situations.

Wilkes and Graeffe do not mention any land animals other than the birds. Mayor on the other hand found a small brown-gray rat, very tame and very abundant, which is probably the Polynesian rat, Rattus exulans (Peale). Besides, he observed a small brown short-tailed lizard that was identified by Thomas Barbour as Lepidodactylus lugubris (Dum. and Bibron). Bryan also noted rats and lizards, but the 1953 survey does not mention the latter.

The only other vertebrates occasionally visiting the land at Rose Atoll are the turtles. Wilkes saw several small ones, "feeding upon a species of fucus that grows upon the reefs." Girard (1858, pp. 459-461) described Chelonia tenuis giving the locality as Honden [Pukapuka, Tuamotus], Tahiti, Eimeo and Rosa Island. He quoted the "Notebook" of the Expedition which said that the turtle captured at Rose "had the alimentary canal crowded with sea-weeds (the Caulerpa seen at Raraka)." Girard's name, Chelonia tenuis was recognized as a synonym of Chelonia mydas L. by Boulenger (1889, p. 182). Rantzau (Graeffe, 1873) gave the best account of turtles:

> "On the sand island, in the months of August and September, a great number of sea turtles came to lay their eggs. Most of them were the common sea-turtle (Chelonia mydas L.). More seldom came the caret (Chelonia imbricata L.). When the time came for the young to hatch, the surrounding sea was full of sharks who avidly snapped up the little turtles as fast as they arrived in deeper water."

The 1953 survey reported evidences of the presence of turtles, but gave no details. It is often recognized that turtles visit some uninhabited islands repeatedly, and natives of certain groups protect these "turtle-islands": thus the Marshallese know that turtles come to Jemo and Bikar, and certain islets of the larger atolls, and had very strict rules concerning them (Tobin, 1952, pp. 23-27). It is to be hoped that Rose Atoll will remain a bird and turtle island.

Very few land invertebrates are recorded from Rose Atoll. Mayor observed a sphinx-moth larva of the genus Celerio (Oken) feeding upon the Portulaca. He also observed a few gnats and flies, but supposed that they might have been introduced by the ship. Most of the reports of Governors' visits, in O Le Fa'atonu, point out the absence of flies and mosquitoes. There are no mentions of insects in the published accounts of the 1938 and 1939 visits. However, Bryan (unpublished field notes) collected small moths, crickets, numerous flies on the Pisonia foliage and adjacent Boerhavia, and ants. The ants were especially noticed by Schultz, who said that they were small, red, nonbiting, but quite a plague because of their enormous numbers. He also noted a small beetle and collected various other insects. Neither of these collections has been identified. On the specimen of Portulaca lutea seen in the U. S. National Herbarium, a scale insect was found. Dr. Harold Morrison, of the U. S. Department of Agriculture identified it as a species of Coccus, very close to or possibly identical with Coccus hesperidum L. The specimen was too poor to permit a more positive determination.

Strangely enough, the only group of Rose Atoll land animals on which some systematic work has been published is that of mites. Ewing (1924) found two species in the fur of some rats sent him from the Bishop Museum in 1920. It is supposed that these were the rats that Mayor mentioned presenting to the Museum. The mites identified were: Laelaps echidnidus Berlese on Rattus sp., Laelaps hawaiiensis n. sp. described from Hawaii (on R. hawaiiensis) but recorded also from Rose on Rattus sp.

Of other invertebrates, Bryan simply reports "the usual hermit-crabs." Schultz collected an earthworm, a very interesting fact, but the specimen has not been identified.

The land fauna of Rose Atoll is undoubtedly larger than is indicated by these sketchy records, and it would be interesting to have a complete investigation of it and to correlate it with the flora, the paucity of which certainly must influence the number of animal species, especially small invertebrates, that can take hold on the atoll. Some larger invertebrates, such as Birgus latro, may be absent because of lack of food.

Conclusion

In many ways, Rose is an unusual atoll. Its pink Lithothamnion reef, and the basalt on it, its interesting soils, its enormous trees, and its curiously small flora and fauna are some of its striking features. More is known about Rose Atoll than about most uninhabited islands, but this knowledge is just sufficient to show that a detailed survey of the little atoll may be extremely interesting and may help us to understand certain features and ecological aspects of larger and more disturbed atolls.

A comparison with Vostok Island, which is very like Rose Islet, with a dense Pisonia forest and some Boerhavia, might be of use to explain some of their common characters. Vostok, unlike Rose Atoll, is very difficult to land on, and therefore no attempt at coconut plantings has been made (Fosberg 1937).

Few undisturbed atolls remain in the Pacific, and the pressure of increasing populations makes the utilization of unoccupied atolls likely. To maintain an example of a natural atoll, it may be suggested that Rose Atoll, so remote, so tiny, so devoid of economic possibilities, except for the fish found in the surrounding water, be protected in its present state. Some measures should be taken to prevent the introduction of coconuts and other fruits, and of animals transported by ships, especially large rats, and to instruct fishing parties in the purpose of conservation. The recent colonization of the almost unstudied Phoenix Islands by Gilbertese with resulting destruction of natural conditions makes urgent the preservation of one of the few undisturbed atolls. Phoenix, McKean, and Birnie Islands had previously been officially declared sanctuaries for birds but have been turned over to these colonists for plantations (Maude, 1952, p. 87). Experience in the Marshalls shows that sea birds, in numbers, do not persist in proximity to human settlements. Conceivably, Rose may soon be the only refuge left for breeding of the sea bird and turtle faunas of the Central Pacific.

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ATOLL RESEARCH BULLETIN

No. 30

The Hydrology of the Northern Marshall Islands

by

Ted Arnow

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THE HYDROLOGY OF THE NORTHERN MARSHALL ISLANDS [1]

By

Ted Arnow [2]

INTRODUCTION

The field work on which this paper is based was carried out in conjunction with an engineering survey of the northern Marshall Islands [3] by the 71st Engineering Survey Liaison Detachment, General Headquarters, Far East Command. The hydrologic studies, which were made by the U. S. Geological Survey, were part of a comprehensive investigation of atoll features. The field work was done in December 1951 and January, February, and August, 1952 during which time the following atolls were visited: Utirik, Taka, Likiep, Ailuk, Lae, Kwajalein, Ujelang, Wotho, Ujae, Taongi, and Bikar (fig. 1). An average of 4 working days was spent at each atoll. The author wishes to acknowledge the assistance of the Marshallese guides and well diggers who aided in collecting ground-water data. In particular he wishes to express appreciation to his colleagues F. S. MacNeil and F. R. Fosberg, who collected water samples on Utirik and Likiep, and C. G. Johnson, who collected water samples on Taongi and Bikar. The author did not visit Likiep, Taongi, or Bikar. Groundwater data for Eniwetok Atoll were furnished by Harry Ladd of the Geological Survey. Appreciation is expressed also to Dan A. Davis, district geologist of the Ground Water Branch, Geological Survey, at Honolulu, Hawaii, who reviewed the report and made numerous valuable comments and suggestions.

A comprehensive report of hydrologic conditions in the northern Marshalls, including a discussion of the principles of the occurrence of ground water on small oceanic islands, is to be incorporated in an extensive report which will include all phases of the investigation. The main purpose of this paper, therefore, is to present factual data collected in the Marshall Islands rather than to give a discussion of principles.

CLIMATE

General Statement

The northern Marshall Islands have a tropical marine climate characterized by uniformity of air pressure, temperature, cloudiness, and humidity. Wind conditions are somewhat more variable, depending upon the season, and precipitation shows considerable variation depending upon the season and latitude. The predominant weather condition is one of moderate easterly trade winds and partly cloudy skys. This is usually broken by relatively brief showers or infrequent thunderstorms. Strong winds and long periods of continuous rain are infrequent, and hurricanes (typhoons) are relatively uncommon.

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[1] Publication authorized by the Director, U. S. Geological Survey.

[2] Geologist, Ground Water Branch, Water Resources Division, U. S. Geological Survey, Agana, Guam.

[3] In this report the "northern Marshall Islands" are considered as comprising Kwajalein Atoll and all atolls north of Kwajalein.

Statistical Data

Meteorological records are comparatively scarce for the northern Marshall Islands. The only continuous long-term data available that were collected before World War II are from Ujelang for the period 1894 to 1913. Since World War II, data have been collected almost continuously at Eniwetok and Kwajalein. Because of the extremely short period of time spent on each atoll, no significant climatological data were collected during the work reported here.

The meteorological factor that has the most bearing on water supply is precipitation. The presence of the equatorial front, which seasonally may extend as far as 11 degrees north latitude, results in a marked gradation of rainfall from south to north in the northern Marshalls because the southern islands are deeper within the front whereas, to the north, the effect of the front becomes progressively weaker. (See fig. 2.) Comparative rainfall data for Ujelang, Kwajalein, and Eniwetok are shown in table 1.

Other climatic data have been published previously. (See references 1 and 4 at end of paper.)

TIDES

Tidal data were obtained at each of the atolls visited, by contract personnel of the 71st Engineers. The data were obtained by hourly observations at a staff gage placed in the lagoon. Approximately 2½ days of observations were made at each atoll. Because of the short term of observations and particularly because of the method of observation, the tide data are unreliable for the determination of a datum plane and therefore can be used only for general comparisons.

Tide data for seven of the atolls visited are published by the U. S. Coast and Geodetic Survey in its annual "Tide Tables for the Central and Western Pacific Ocean." These data are based on a primary station established at Kwajalein Island, Kwajalein Atoll. At Kwajalein the mean tide range, as measured in the atoll lagoon, is 3.5 feet; the spring range is 5.0 feet. There are some differences between the ranges at Kwajalein and those of some of the other atolls. The greatest difference from the average is at Ujelang where the mean range is 2.8 feet and the spring range is 3.9 feet.

WATER SUPPLY

Rain Water

Rain water is the most important source of fresh water for the Marshellese people. They prefer to use it for all purposes, but during the dry season the available rain water is reserved for drinking purposes and water from wells is used for washing and cooking.

The bulk of the rain water is caught on corrugated iron sheets hung over concrete cisterns or corrugated iron roofs of houses or other buildings. The

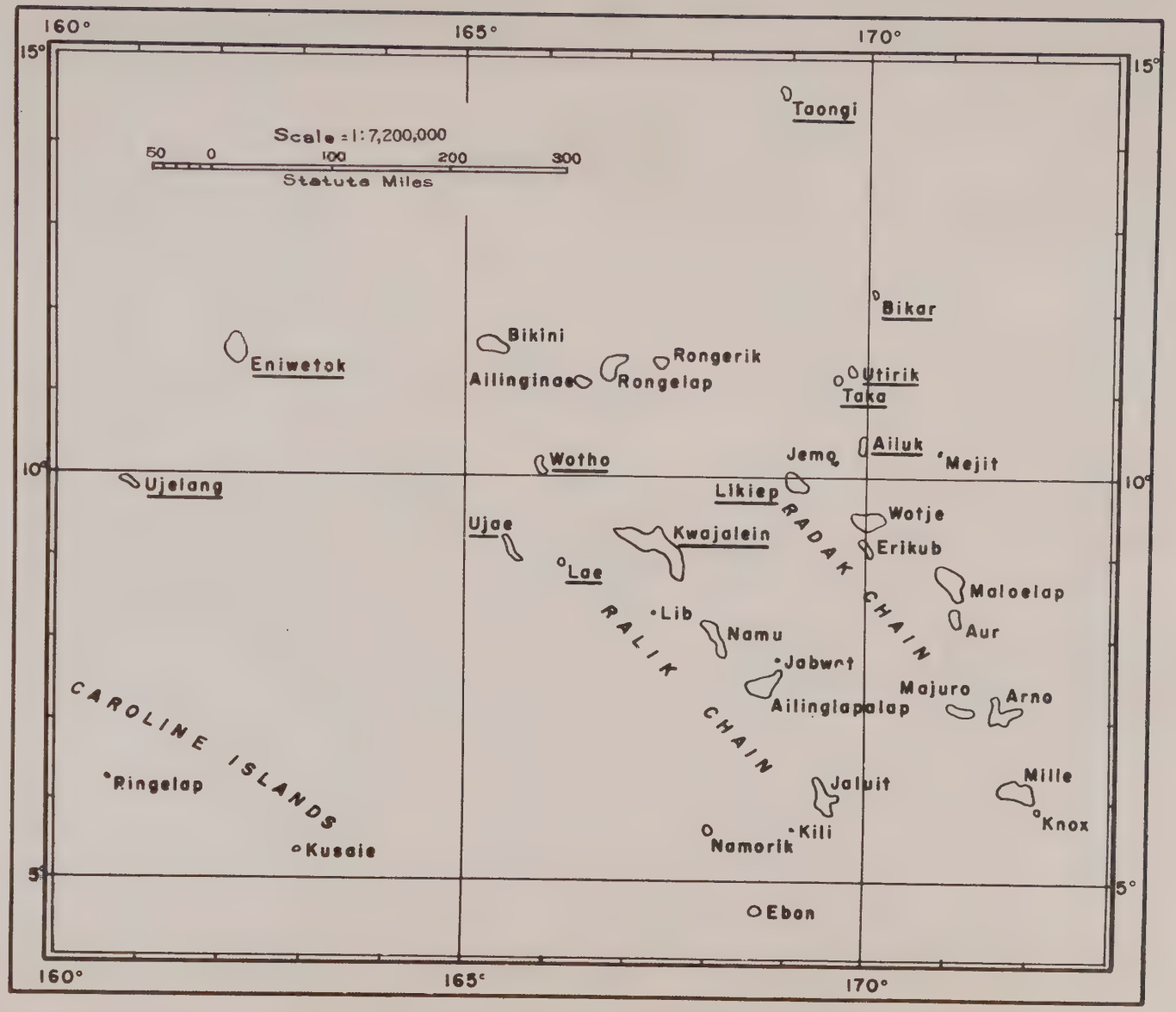

Figure 1. -- Outline map of the Marshall Islands. Islands covered in report are underlined.

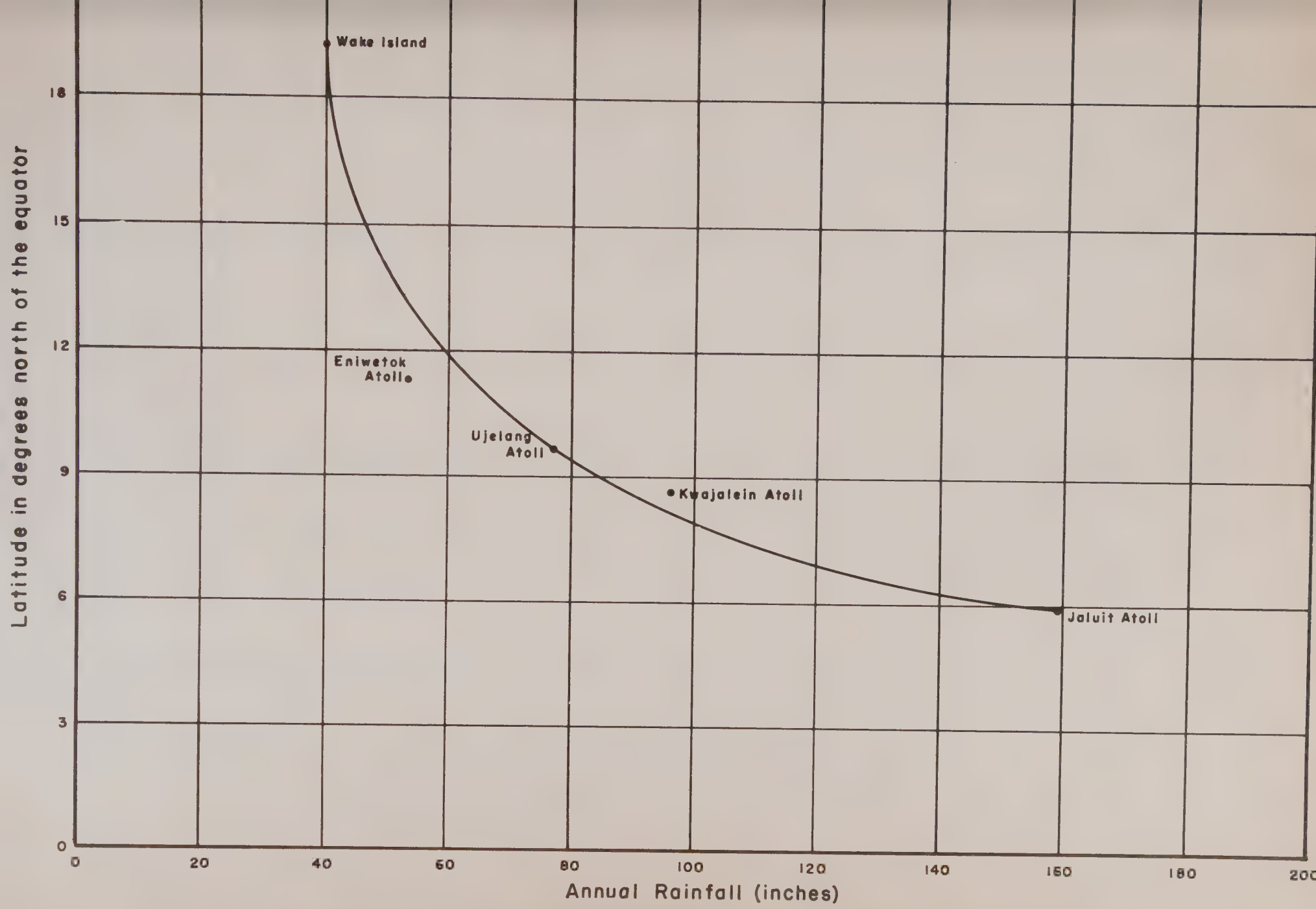

Figure 2.--Variation of rainfall with latitude in the Marshall Islands.

Table 1.--Comparative precipitation data for Eniwetok, Ujelang, and Kwajalein Atolls, Marshall Islands.

Eniwetok Atoll. Length of record: 5 years, 1944-1946, 1949-1953.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly	0.80	0.71	2.63	2.54	6.22	2.47	5.54	6.38	6.00	9.18	4.61	2.31	49.39
Minimum monthly	0.12	0.39	0.39	0.22	1.40	1.06	2.34	3.00	2.79	5.19	2.51	0.79	
Maximum monthly	1.57	1.30	6.21	10.71	14.89	7.72	12.89	9.05	12.85	14.15	6.56	3.77	

Kwajalein Atoll. Length of record: 8 years, 1944-1953

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly	3.97	2.20	7.39	3.87	8.44	7.39	7.67	9.14	10.78	11.80	11.25	11.76	95.66
Minimum monthly	1.16	0.61	0.59	0.43	4.25	2.26	2.54	4.45	5.04	3.02	4.40	5.10	
Maximum monthly	15.66	5.13	24.33	9.40	15.88	13.02	13.20	16.95	17.38	20.10	16.76	30.33	

Ujelang Atoll. Length of record: 16 years, 1894-1913.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly	2.1	1.8	2.6	5.2	6.6	7.1	8.4	8.5	10.3	10.4	9.6	4.8	77.4
Minimum monthly	0.7	0.3	0.4	0.6	0.8	0.8	2.9	3.4	6.1	5.6	3.0	1.9	
Maximum monthly	7.3	6.6	10.6	14.2	14.3	23.2	18.5	14.1	16.3	14.3	24.3	8.5	

water is stored in the cisterns and in oil drums. Where corrugated iron is not available, rain water is obtained by collecting the water that falls on coconut palms, or occasionally, Pandanus trees. The water caught on trees is stored in drums or any other available receptacle, such as paint cans or wash basins.

No determined effort is made by the Marshallese people to insure a year-round supply of rain water. Extensive roof areas are unguttered and some of the cisterns are fed by catchment areas that are not large enough to supply the maximum amount of water that could be handled by the cistern. If maximum use were made of existing facilities there would be much less likelihood of the exhaustion of rain-water supplies that now occurs frequently during the dry season.

No samples of rain water were caught on a surface previously tested to make sure it was free of salt. Samples obtained directly from cisterns ranged in chloride content from 20 parts per million on Lae to 60 parts per million on Wotho. The total hardness of these two samples was 80 and 70 parts per million, respectively. A sample obtained on Lae from an oil drum fed from catchment on a palm tree had a chloride content of 60 parts per million and a total hardness of 40 parts per million.

Ground Water

Physical nature.--The only source of fresh water on any island in the northern Marshalls is the rain that falls directly on that island. Part of the rainfall evaporates or is transpired by plants, and the remainder, because of the high permeability of the island sediments, seeps directly into the ground. There is no significant surface runoff. The fresh water, which is about 40/41 as heavy as salt water, floats on the surface of the salt water roughly in the shape of a dome, the edges of which coincide with the edges of the island. The fresh water displaces a volume of salt water equal to its own weight and depresses the fresh-salt-water interface below sea level under the island. Under ideal conditions in a homogeneous island, because of the 40/41 weight relationship of fresh to salt water, the interface extends about 40 times as far below sea level as the dome stands above sea level. Actually, the shape of the fresh-water body varies, depending upon local geologic conditions, and the 40-to-1 depth ratio is modified by a transition zone of variable thickness in which there is a mixture of fresh and salt water. This double-convex fresh-water body floating on sea water is known as the Ghyben-Herzberg lens. It is the only source of potable ground water in the northern Marshall Islands.

The average height of fresh water above mean sea level in the northern Marshall islands is less than 1 foot. At well 7, on Lae Island, Lae Atoll, which is about 1,035 feet from the lagoon shore, the mean height of water above mean sea level was found to be 1.41 feet. This figure is based on the determination of mean sea level by tide gage. Unfortunately, the tide-gage determinations were such that the accuracy of the calculated heights of levels in the well is highly questionable. Theoretically, therefore, the depth of fresh water below sea level in the islands of the atolls generally is not more than about 40 feet at the deepest point, tapering to zero at the edges of the lenses. Because of the mixing effect in the zone of transition, however, only the upper part of the lens is fresh enough for human consumption.

Fresh water is miscible with salt water, and the Ghyben-Herzberg lens will not form or will be destroyed unless certain prerequisites of permeability, water-level fluctuation, and precipitation are fulfilled. The permeability of the soil and rocks constituting the island must be great enough to allow the fresh water to infiltrate rapidly enough to maintain a positive hydrostatic pressure against the salt water, but must not be so great as to allow free mixing of the fresh and salt water. The islands in the northern Marshalls consist mostly of sand overlying rubble deposits, both of which have a degree of permeability that is conducive to the formation of a Ghyben-Herzberg lens. The windward side of many of the islands, however, is composed of coarse-grained materials ranging in size up to boulders, and because of the high permeability of these materials the lens may not be developed as well on the windward side as it is on the leeward side or in the central part of an island. At Taka Island, Taka Atoll, water from well 6, which is on the windward side of the island, had a chloride content of 6,480 parts per million, whereas water from wells 1 and 7, on the leeward side, had chloride contents of 840 and 2,480 parts per million, respectively. This condition existed in spite of the fact that well 6, at 400 feet, is farther from the windward shore than wells laand 7, at 300 and 55 feet respectively, are from the lagoon shore.

The second prerequisite for a functioning Ghyben-Herzberg lens is that tidal and seasonal fluctuations in the ground-water level be small, thereby reducing the mixing of fresh and salt water. The magnitude of the tidal fluctuations in the ground-water body at a given point in an island is inversely proportional to the distance to the shoreline and directly proportional to the permeability of the soil and rocks constituting the island. A comparison of tidal fluctuations in the ocean and in the ground-water body in four islands indicates that the ocean tides are damped by approximately nine-tenths as they move through the land (see table 2). Presumably in smaller islands there would be considerably less damping of the ocean tides. Inasmuch as each atoll was visited only once it was not possible to obtain any data concerning the magnitude of seasonal or annual fluctuations of the levels of the fresh-water lens.

The third prerequisite for the existence of a Ghyben-Herzberg lens is that the precipitation be sufficient to provide adequate infiltration of water to the ground-water body after losses due to evaporation and transpiration are deducted. It is estimated that less than half and perhaps only about a quarter of the rainfall is available after evapo-transpiration losses are deducted. The infiltration areas are small, owing to the size of the islands, and, in addition as shown in figure 2, the precipitation in the northernmost Marshall Islands is light. The total recharge to the ground-water lens, therefore, is so small in the northernmost islands that a permanent Ghyben-Herzberg lens probably does not exist on any island north of the latitude of Eniwetok Atoll. South of Eniwetok infiltration from rainfall is adequate to maintain a permanent lens if the island is at least 0.1 square mile in area. This area is great enough to provide sufficient catchment area, and adequate width for the damping of tidal fluctuations. During the rainy season smaller islands south of Eniwetok and larger islands north of Eniwetok may receive enough precipitation to build up small fresh-water lenses, but these lenses deteriorate or are destroyed during the dry season because of the lack of sufficient water from precipitation to maintain them against natural discharge and mixing with the ocean water.

Table 2.--Comparison of tidal fluctuations in the ocean and in the ground-water lens of four islands in the northern Marshall Islands.

Island	Well number	Distance to lagoon shore (feet)	Maximum tidal range in well (feet)	Mean tidal range in well (feet)	Maximum tidal range in ocean (feet)	Mean tidal range in ocean (feet)	Ratio of mean tidal range in well to mean tidal range in ocean	Period of observation (days)	Chloride content of well water (ppm)
Ailuk	1	115	0.62	0.32	5.8	4.0	0.08	5	272
Lae	7	1,035	.22	.16	3.5	2.1	.08	3	15
Ujelang	2	140	.23	.20	3.0	1.7	.12	3	100
Wotho	4	330	.26	.22	5.1	4.8	.05	1.5	130

Quality of water.--The extent of development of the Ghyben-Herzberg lens controls the quality of the ground water found in the islands of the northern Marshalls. Where there is a combination of such factors as low rainfall and small island area (conditions inimical to the development of a Ghyben-Herzberg lens) as is found for example on Bogallua Island, Eniwetok Atoll, the ground water is very similar to sea water in composition. On a larger island such as Lae Island, Lae Atoll, however, where the precipitation is considerably greater, the ground water in the central part of the island is comparable, in certain dissolved constituents, to water obtained by rain catchment. Between these extremes may be found ground water having varying chemical characteristics, depending upon the development of the Ghyben-Herzberg lens and the location with respect to the shoreline. (See table 3.)

All the 53 ground-water samples tested in the northern Marshalls had a total hardness of more than 200 parts per million 1/ and 50 exceeded 300 parts per million. The relation of total hardness to distance from the shoreline was not the same in every island. Two examples are shown in figures 3 and 4. At Ailuk Island, Ailuk Atoll, the total hardness varied inversely with distance from the lagoon shore, whereas at Lae Island, Lae Atoll, the total hardness of the samples tested remained approximately uniform and showed no relation to distance from the shoreline.2/ The increase in total hardness at Ailuk toward the lagoon shore is apparently due to contamination by sea water mixing with the ground water. At Ailuk the calcium hardness of the ground water remained relatively constant, regardless of distance to the shoreline, whereas at Lae the calcium hardness seemed to decrease toward the shore (figs. 3 and 4). The increase in total hardness at Ailuk, where the calcium hardness remained constant, and the decrease in calcium hardness at Lae, where the total hardness remained constant, must be accounted for by an increase in magnesium hardness.

The chloride content of the ground water varies widely, depending upon the amount of contamination by sea water. The chloride content of sea water is approximately 18,000 to 20,000 parts per million, whereas that of rain water theoretically is zero. The rain water, however, dissolves salt crystals floating in the air and deposited on the vegetation and soil. Therefore, a "base" chloride content is always present regardless of whether the ground water has been contaminated by sea water. The lowest chloride determination obtained, 15 parts per million, was at well 7 in Lae Island (see table 3), and this may be considered as the base chloride content in the northern Marshalls until and unless a lower determination is obtained. The highest value obtained was for a well on Bogallua Island, Eniwetok Atoll, where the chloride content of a well sampled was 19,300 parts per million (see table 3). Chloride of about this magnitude, of course, is present in the ground water of most of the small islands in the northern Marshalls on which fresh-water lenses have not formed. In places the ground water on the main islands in Likiep, Lae, Ailuk,

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1/ Water having a hardness of less than 50 or 60 parts per million is generally rated as soft. Where the hardness is 200 or 300 parts per million it is common practice in the United States to soften water for household use.

2/ Ailuk and Lae are used as type examples because the most satisfactory well distribution was obtained on these islands.

Wotho, Eniwetok, and Ujae atolls was found to contain less than 250 parts per million of chloride, and on Utirik, Ujelang, and Kwajalein Atolls to contain less than 500 parts per million of chloride. Such waters are definitely potable and contain considerably less dissolved mineral matter than is present in public water supplies in parts of Guam and in certain other islands in the Pacific.

On some of the larger islands the chloride content of the ground water was found to be controlled by the distance of the point of sampling from the shoreline. On both Ailuk and Lae Islands there was an inverse relationship between chloride content and distance to Lagoon shore (fig. 5). On other islands, notably Wotho Island, Wotho Atoll, and Lado Island, Likiep Atoll, however, no such relationship was observed.

As would be expected in islands composed almost exclusively of limestone or limestone derivatives, the ground water is slightly alkaline (see fig. 6). The average pH of 50 samples tested was 7.4. Of the total, 45 had a pH between 7.0 and 8.0 and 39, between 7.2 and 7.6. Two of the samples had a pH of 6.7, which is slightly on the acid side. Both samples were obtained from pits on Lae Island dug in taro plots where the soil was a mucky peat containing much decaying vegetal matter. Two of the samples had a pH of 8.3. This, however, was due to the influence of sea water. The two samples were obtained from wells on Sibylla Island, Taongi Atoll, where the ground water had salinities corresponding to 65 and 85 percent of that of ocean water, which may be expected to have a pH ranging from 8.1 to 8.3. One sample, with a pH of 8.2, was from a well on Engebi Island, Eniwetok Atoll. The high pH value probably was caused by the concrete lining in the well. This effect of concrete, which evidently still is curing, was noted also in several samples of rain water collected from concrete cisterns. Five such samples showed pH values ranging from 8.0 to 8.5, whereas one sample of rain water that had been stored in a discarded oil drum had a pH of 7.4.

The temperature of the ground water in the northern Marshall Islands averaged 81° Fahrenheit. This is 1 degree less than the mean annual air temperature (based on records for Ujelang Atoll). No relationship between temperature of the ground water and latitude of the atoll was observed.

Use.--Ground water is used by the Marshallese people for all domestic purposes. Although rain water is preferred, ground water is used for washing and cooking during the dry season and for drinking purposes when the rain cisterns are completely empty.

All the ground water is obtained from dug wells. Most of the wells are less than 10 feet deep and penetrate about 1 foot below the water table. Many of the wells are cased with limestone blocks or discarded oil drums, but some of the very shallow ones are not cased at all. None of the wells was reported to antedate the German period of control and it is unlikely that the Marshallese people were aware of the presence of fresh water under their islands before the German period. Even today on Lae Island, where there is an excellent Ghyben-Herzberg lens, some of the Marshallese were skeptical of the widespread existence of fresh water beneath the island. They showed considerable surprise when a well dug through the boulder rampart near the ocean side of the island yielded fresh water.

Table 3.--Chemical analyses of water from selected wells in the northern Marshall Islands
(Analyses by U. S. Geological Survey. Dissolved constituents in parts per million)

Island Well no. Atoll	Ailuk 1 Ailuk	Engebi 1 Eniwetok	Engebi 2 Eniwetok	Engebi 3 Eniwetok	Engebi 4 Eniwetok	Runit 1 Eniwetok	Biijiki 1 Eniwetok	Bogallua 1 Eniwetok	Lae 1 Lae	Lae 7 Lae	Wotho 4 Wotho	Wotho 7 Wotho	Wotho 8 Wotho
Distance from shore (ft.)	115	925	410	710	250	175	65	40	345	1,035	330	210	490
Area of island (sq. mi.)	.19	.38	.38	.38	.38	.13	.08	.03	.21	.21	.09	.09	.09
Specific conductance (micromhos at 25°C)	1,390	1,470	1,630	1,040	8,070	14,800.	14,200	42,500	354	589	786	824	872
Dissolved solids	767	a800	a890	a570	a5,200	a10,200.	a9,800	a31,900	201	406	421	546	473
Hardness (total, as $CaCO_3$)	464	432	324	388	1,000	1,920	1,800	6,400	148	380	370	380	310
Silica	---	14	9.4	8.5	9.9	9.0	8.5	4.1	---	---	---	---	---
Iron	.02	.07	.27	.11	---	---	---	---	.02	.02	.02	.02	.03
Calcium	30	---	---	---	---	---	---	---	41	145	54	40	50
Magnesium	54	---	---	---	---	---	---	---	11	2.7	28	80	24
Sodium	---	31	46	77	1,500	2,850	2,700	10,600	---	---	---	---	---
Potassium	---	8.0	6.0	5.4	48	70	70	200	---	---	---	---	---
Sulfate	81	62	83	40	17	43	36	132	12	9.1	17	54	30
Chloride	272	222	326	88	2,680	5,200	4,860	19,300	44	15	130	156	129
Nitrate	---	50	.3	46	12	10	10	2.0	---	---	---	---	---
Phosphate	---	.2	.0	.0	.0	.1	.1	.2	---	---	---	---	---
pH	8.0	7.4	7.7	7.3	8.2	7.6	---	7.8	7.4	6.7	7.2	7.2	---
Temperature (°F)	78	79	77	79	79	75	77	82	79	80	81	81	82

a Calculated from specific conductance.

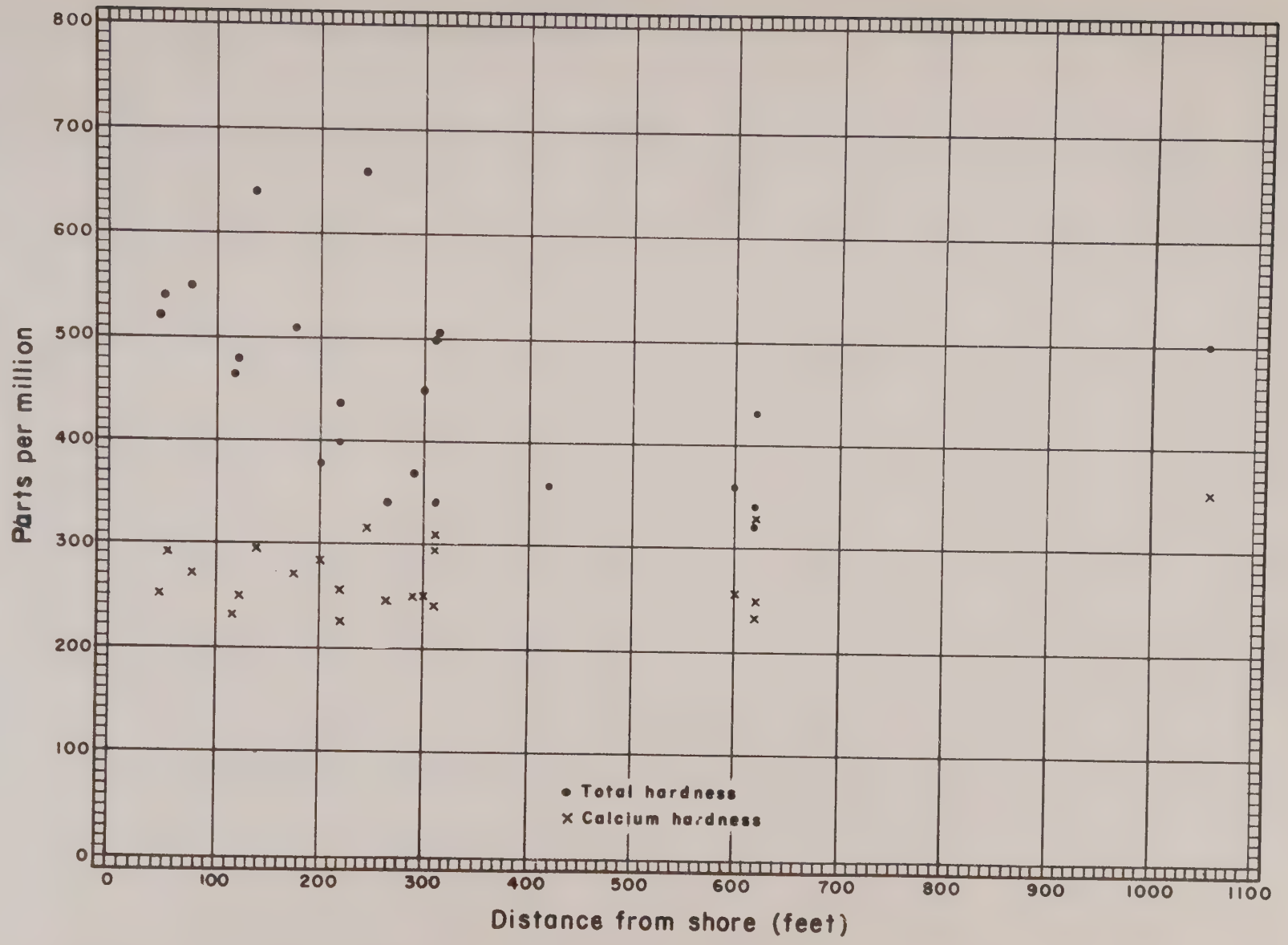

Figure 3.--Relation of total hardness and calcium hardness to distance from shoreline in the ground water of Ailuk Island, Ailuk Atoll, Marshall Islands.

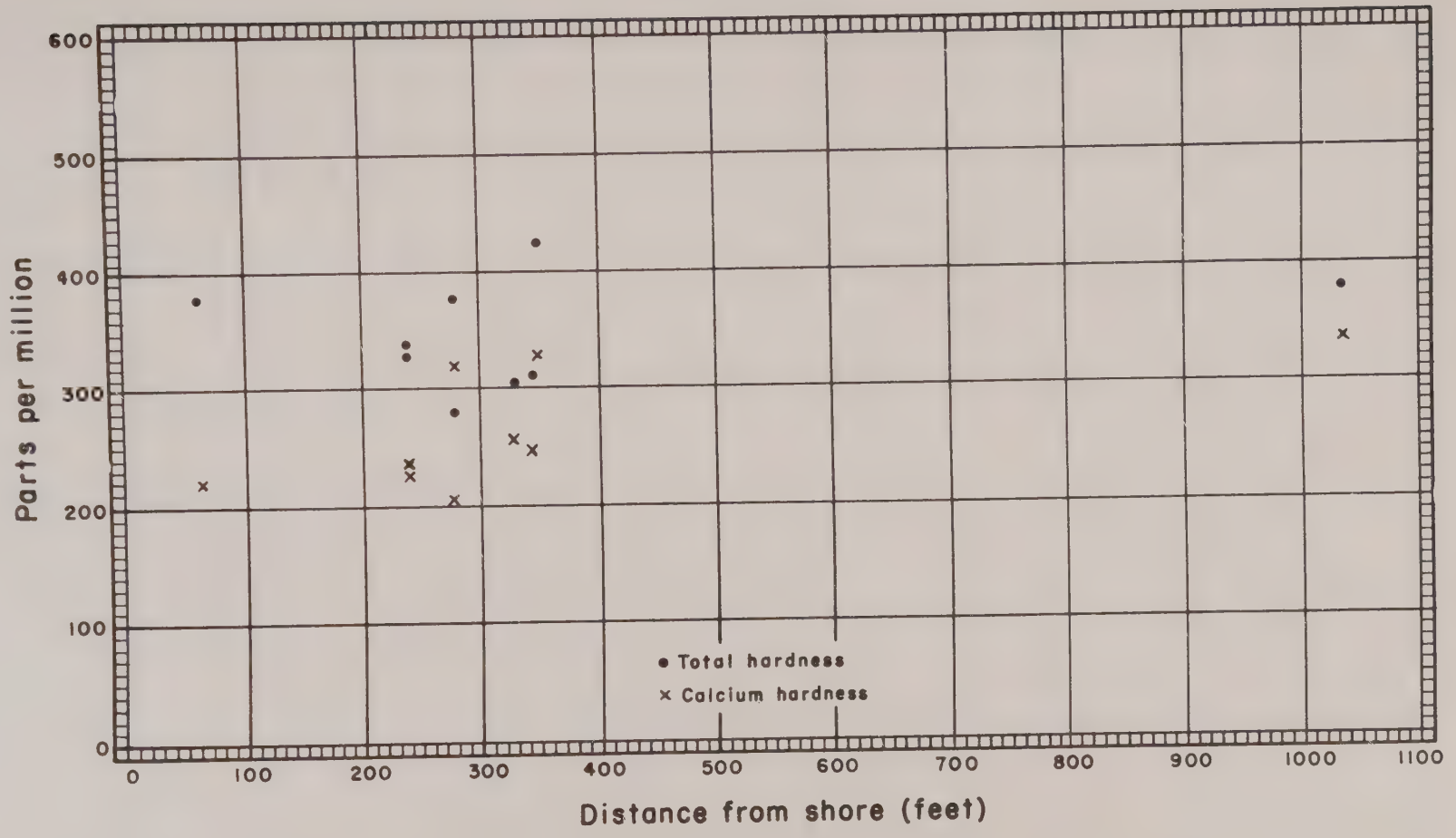

Figure 4.--Relation of total hardness and calcium hardness to distance from shoreline in the ground water of Lae Island, Lae Atoll, Marshall Islands.

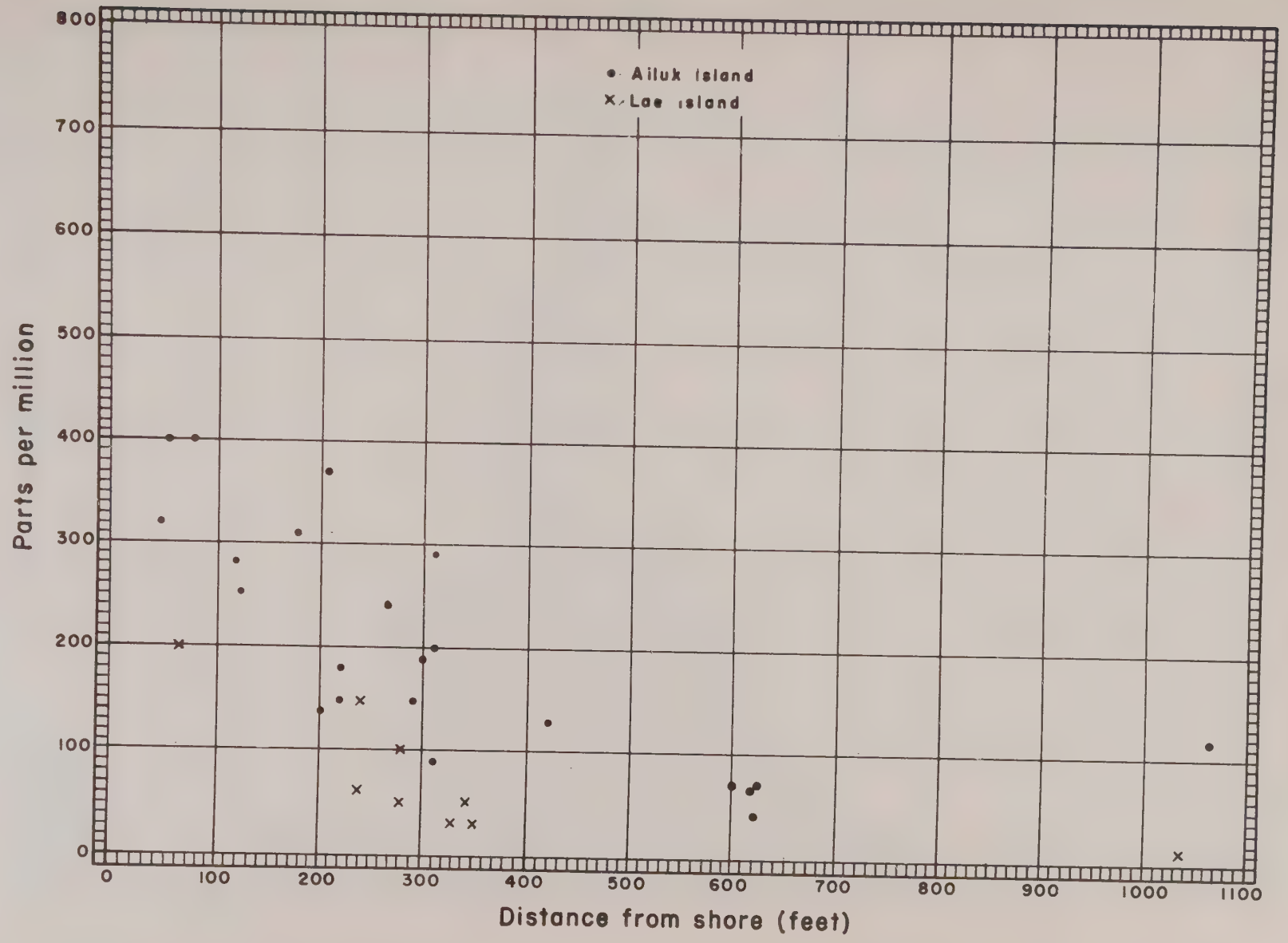

Figure 5.--Relation of chloride content to distance from shoreline in the ground water of Ailuk Island, Ailuk Atoll, and Lae Island, Lae Atoll, Marshal Islands.

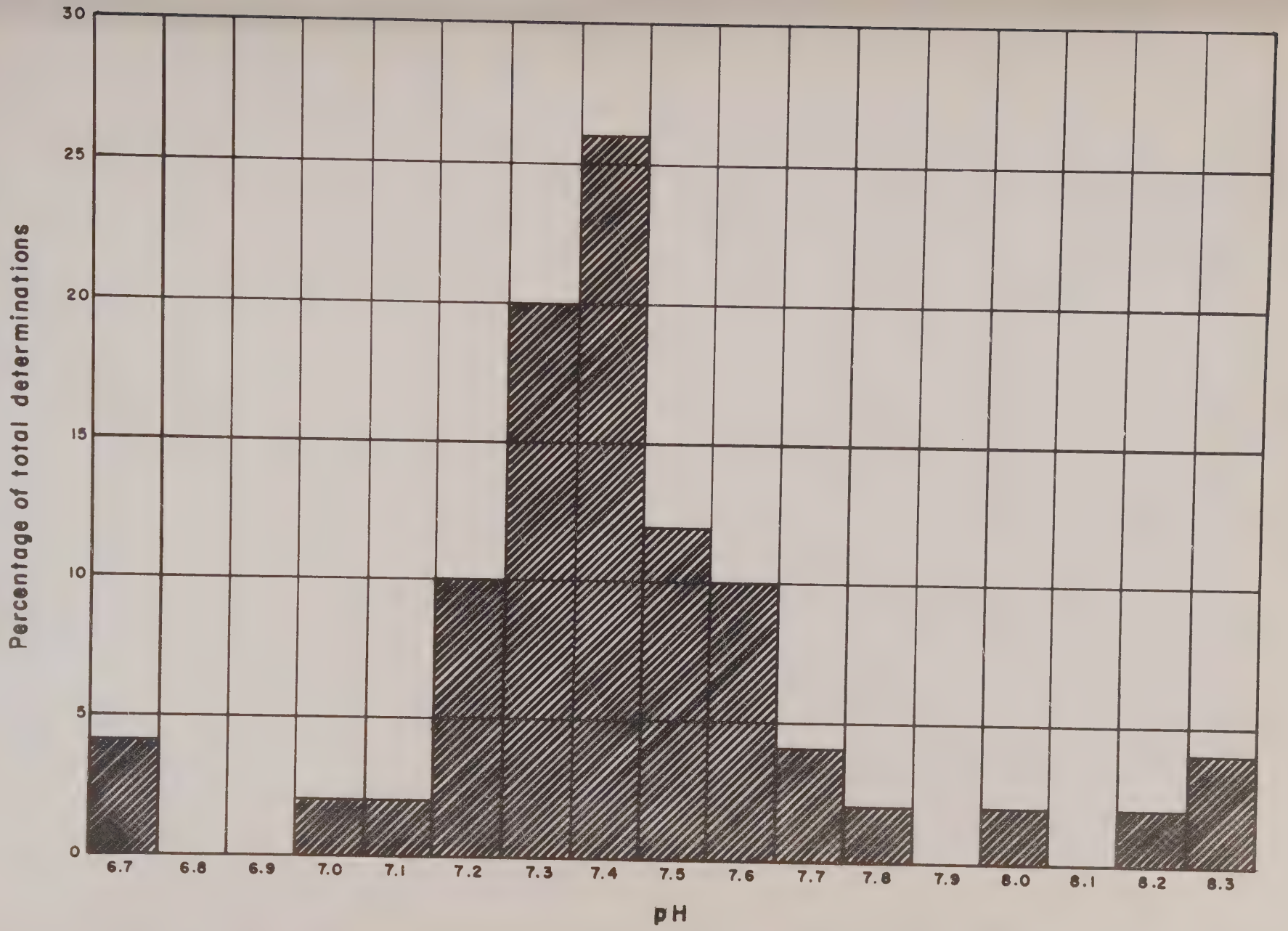

Figure 6.-- Histogram of 50 pH determinations of ground water in the Marshall Islands.

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